SOIL AND TOPOGRAPHIC FEATURES AFFECT PLANT GROWTH ON A NATURAL GAS PIPELINE RIGHT-OF-WAY IN NORTHEASTERN BRITISH COLUMBIA

by

Toby Turner

B.H.Sc., Flinders University of South Australia, 2000
B.Pl., University of Northern British Columbia, 2011

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
FORESTRY

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

June 2016

Abstract

Natural gas reserves in northeastern British Columbia (B.C.) are being extracted, yet the effects to soils and plants from industrial disturbance in the region are poorly understood. This study examined soil and topographic factors that affect plant establishment and growth on a reclaimed natural gas pipeline. The study area was located approximately 70 km southeast of Tumbler Ridge, B.C. Field sampling took place between spring 2012 and summer 2013. Soil properties were examined to understand growing conditions at the site, natural regeneration was observed to understand current species diversity, and growth parameters were taken for lodgepole pine and shrubby cinquefoil. Soil nutrients were bigher in wetland blocks than upland blocks, and were associated with greater species diversity. Plant growth was greatest in north-facing blocks, however biomass was greatest in crest blocks. Reliance on natural revegetation can delay site recovery, and reclaiming a site requires site-specific plant species in northeastern B.C.

Table of Contents

List of Tables

List of Figures

List of Acronyms

ALC- Agricultural Land Commission

ALR- Agricultural Land Reserve

BWBS- Boreal White and Black Spruce

BC- British Columbia

BC MFLNRO- British Columbia Ministry of Forests, Lands, and Natural Resource Operations

BCOGC- British Columbia Oil and Gas Commission

CEC- Cation Exchange Capacity

CWD- Coarse Woody Debris

ESSF- Engelmann Spruce Subalpine Fir

GPS- Global Positioning System

HDR- Height-Diameter Ratio

IOGC- Indian Oil and Gas Canada

LFH- surface litter (organic horizon on mineral soil)

MRD- Minimum Replacement Depth

NEB- National Energy Board

OM- Organic Matter

ROW- Right-Of-Way

SDI- Shannon Diversity Index

SOH- Stem Only Harvest

TCF- Trillion Cubic Feet

TOC- Total Organic Carbon

UNBC- University of Northern British Columbia

Acknowledgements

I would like to express my heartfelt gratitude to my supervisors, Dr. Chris Opio and Dr. Mike Rutherford for their guidance and supervision; and my committee members Hugues Massicotte and Stephane Dubé for their vital feedback and assistance with soil and plant identification; Shell Canada for funding this project, Mark Sherrington of Shell Canada (Calgary); the University of Northern British Columbia Seed grant for additional funding; Tim Gurlitz, Steve Rogers, Cory Hagen and Dustin Listhaeghe of Shell Canada (Grande Prairie) for issuing work permits for monitoring. My thanks also go to Andrew Carpenter of Reclaimit Ltd. for my understanding of the planting methodology used at the sites, and ongoing guidance.

Other people at UNBC I would like to thank are Paul Sanborn, soil science professor, for use of soil classification forms and guidance; and John Orlowsky and Doug Thompson for granting me access to the Enhanced Forestry Laboratory (EFL) for plant and soil preparation for analysis. I would also like to thank Dr. Che Elkin for help with statistics.

I would also like to thank my Research Assistant Ewing Teen for his invaluable field help, and Dean Zimmer of the BC Oil and Gas Commission (Fort St. John) for lending me field assistants (Cierra Hoecherl and Emilia Sasso) at very short notice in 2013. Further thanks go to Stephane Dubé, Bethany Wood, and Veronique Dubé (BC Ministry of Forests Lands and Natural Resource Operations- Omineca Region) for help and guidance with soil data collection and analysis.

Lastly, I would like to thank Kari Harder (University of Alberta), for much needed help with statistical analysis and for keeping me sane throughout this process.

1.0 General Introduction

There are extensive natural gas reserves in northeastern British Columbia (B.C.). This resource has attracted major oil and gas players to the region, and many companies have existing infrastructure for extraction and transfer of natural gas. Reclamation requirements are in force, and general guidelines are available to industry; some companies are more proactive in their efforts for improved reclamation practices that enhance vegetation recovery beyond jurisdictional requirements. Beyond present guidelines, there are opportunities to optimize best practices for soil handling and re-creation of plant communities, especially in mountainous and subalpine environments.

1.1 Research Objectives

Exploration and extraction of western Canada's natural resources continues to be a national economic driver, and natural gas reserves are found in abundance in this area of the country (BC Ministry of Energy, Mines and Natural Gas, 2012). Recent declines in commodity prices have however, slowed exploration of natural gas. A significant proportion of extraction of natural gas takes place in northeastern B.C. As more deposits of gas are explored and extracted, the cumulative footprint of industrial disturbances grows (Foote and Krogman 2006; Olson and Doherty 2012), and so does the need to reclaim natural gas infrastructure.

Like many other companies, Shell Canada has goals and requirements for re-creating wildlife habitat and restoring environmental quality following the installation of pipelines. Part of this comes from federal and provincial environmental legislation regarding reclamation of industrially disturbed sites (Noble 2006), and from within the company's stewardship role for restoring environmental integrity to a site disturbed for resource extraction. Southern populations of woodland caribou (*Rangifer tarandus caribou*) are threatened in part by human activities including pipeline development (Edmonds 1998; Polfus *et al.* 2011; Seip 1998), and recent attention to these wildlife populations means that reclamation of sites along migration routes of caribou should include re-establishment of critical, appropriately vegetated habitat (EC 2012; Polfus *et al.* 2011).

The reclamation work undertaken by an oil and gas company, pipeline company or reclamation contractor may also tie in with other long-term goals, such as addressing how resource extraction, pipeline installation and reclamation activities impact First Nations' use of the land. Traditional use of lands may include hunting and use of certain plant species for medicinal purposes or food. Meaningful consultation with First Nations is a part of the B.C. environmental review process for obtaining approval for a specific project (Wyatt 2008), and understanding the cultural practices of Nations affected by industrial development should be integral to assisting with industry's reclamation goals (Baker and McLelland 2003; Booth and Skelton 2011).

Depending on specific environmental factors, natural gas developments that affect surficial horizons of forests and wetlands may take place during winter, when machinery operating on frozen soils reduces potential for soil compaction and its associated effects on soil physical characteristics such as air porosity and bulk density (Petter *et al.* 2009), and resources lost through stuck machinery. A confounding factor for development is that climatic conditions of the Peace region of northeastern B.C. include periodic freeze thaw cycles during the winter months due to warming foehn or "Chinook" winds. These wind events increase ambient temperatures for a period of time, melt snowpacks, and thaw topsoil layers (Bullock *et al.* 2001; Walker *et al.* 2006), which can create conditions for winter desiccation impacts to some plant species. This highlights the importance of considering climate related factors when planning reclamation strategies.

Although research and guidelines exist for reclamation best practices of various landscapes in western Canada (Desserud *et al.* 2010; Desserud and Naeth 2010; Naeth *et al.* 1987), there are knowledge gaps in understanding optimal reclamation and revegetation strategies at a micro site level on pipeline rights-of-way (ROWs) in the Peace region of northeastern B.C. In this region, it is not known which native plants species are best suited to specific site conditions, or if natural regeneration is a sufficient strategy to re-establish vegetation at sites following creation of right-of-ways and installation of pipe trenches. Replanting programs can be expensive, and natural regeneration may not be a suitable option for re-establishing vegetation at these sites. Further, use of plant species native to the site and region, and mitigation of soil disturbances common to industrial activity may lead to improved survival and growth of plant species used in reclamation projects.

This research assessed soil properties, topographic features and plant growth and survival on a reclaimed pipeline right-of-way in northeastern B.C. Within the pipeline right-of-way context, the objectives of the study were to: (i) describe soil chemical and physical properties, and topographic factors present; (ii) investigate plant species diversity, as forest plant species heterogeneity may be an indicator of improved ecosystem health (Lindenmayer *et al.* 2000; Niemi and MacDonald 2004); and (iii) observe annual changes in plant growth, which is an indicator of site recovery (Cieszewski and Bella 1989).

1.2 Organization of Thesis

This thesis is organized in a manuscript format. Chapter One provides the context for the study with respect to vegetation communities found in the boreal region of northeastern B.C. Chapter Two is a literature review of natural gas extraction sites in the Peace region of B.C., and the challenges of reclaiming linear disturbances and substrate alterations caused by construction of buried pipelines. Chapter Three presents information on the Ojay pipeline and the experimental design of right-of-way research blocks used in this study. Chapter Four presents detailed information on soil and topographic properties observed at the research sites. Chapter Five examines plant species diversity using the Shannon Diversity Index in the research blocks along the right-of-way. Chapter Six examines plant growth, determined by height, stem diameter and plant biomass in research blocks along the right-of-way. Chapter Seven provides a summary of the results of the study, the significance of the research findings to literature and industry, limitations of the study, and recommendations for reclamation practice and directions for future research.

2.0 Literature Review

The ecologically critical boreal forests of the northern hemisphere are found through much of Canada, including the northeastern region of B.C. Natural gas is found in the region of B.C., and extraction of the resource in recent years has fragmented forests, altered soil properties, and disrupted cultural use of the land base. Recent revisions to reclamation practice have improved vegetation recovery, although substantial challenges remain in terms of mitigating industrial impacts in montane ecosystems in northeastern B.C.

2.1 Boreal Forests

Canada has approximately 30 % of the world's boreal forests and they encompass approximately one third of Canada's land mass (Brandt 2009; NRC 2012; Smith *et al.* 2003). Recognized as being of particular importance in a global context, the connectivity of boreal forests in Canada are being altered through resource development (Lee and Boutin 2006). Boreal forests are dynamic in that they undergo a variety of natural disturbances, such as fire and insect outbreaks (McCullough *et al.* 1998). Approximately five to six million hectares of Canada's boreal forests are disturbed by fire, insects and disease events per year, allegedly five to six times the area of boreal forest that experiences disturbance from construction of pipeline right-of-ways over the same time period (Bose *et al.* 2014; NRC 2012).

The south Peace region of northeastern B.C. incorporates a portion of Canada's boreal forest. The Boreal White and Black Spruce (BWBS) biogeoclimatic zone in northern B.C. includes the eastern slopes of the Rocky Mountain range to the Alberta plains in the northeastern corner of B.C., and lower (below 1100 metres above sea level) elevations of northwestern B.C., incorporating approximately ten percent of the B.C. landmass (DeLong *et al.* 1991; Prescott *et al.* 2000).

Industrial disturbances do not necessarily mirror natural disturbance patterns (Bergeron *et al.* 1999) experienced by forest ecosystems. Natural gas exploration activity in the northern regions of B.C. has been extensive, and its footprint alters forest landscapes (Graf 2009; Lee and Boutin 2006; Lovich and Bainbridge 1999; MacDonald *et al.* 2012). The harvest of strips of forest stands for pipeline sites create linear corridors, and pipeline installations disturb soils through construction of trenches for laying underground pipes. Tree harvest and removal, and substrate disturbance for installation of pipelines, create numerous challenges for right-of-way reclamation.

The benefits of reclaiming pipeline rights-of-way are not limited to restoring vegetation and soil quality. Boreal forests in western Canada also provide critical habitat for charismatic animal species such as grizzly bear (*Ursus arctos horribilis*) (Garshelis *et al.* 2005), and southern populations of woodland caribou (*Rangifer tarandus caribou*) (Wittmer *et al.* 2007). Populations of these species continue to decline in part due to direct and indirect ramifications of human activities (Festa-Bianchet *et al.* 2011; Laberee *et al.* 2014; McLoughlin *et al.* 2003). Therefore, reclamation strategies need to consider habitat requirements of wildlife when planning reclamation of pipeline rights-of-way.

Boreal forests in western Canada are host to a variety of tree species including lodgepole pine (*Pinus contorta* var. *latifolia*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), balsam poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*) and white (paper) birch (*Betula papyrifera*) (Thompson and Pitt 2003). Forest practices also play a role in the composition of canopy species in forest stands (Barbier *et al.* 2008). In B.C., lodgepole pine, with its range of tolerance of nutrient and moisture regimes, plus its natural occurrence in interior regions, has been the principal tree species preferred for mainland timber production (Brockley 1990; Coupé *et al.* 1991). This species has been planted extensively in interior regions of the province, and estimates suggest over fifty percent of interior forests are planted with lodgepole pine (Mather *et al.* 2010).

Understory vegetation is another integral component of a forest ecosystem (Chavez and Macdonald 2010) and species composition of forest understory is a key indicator of site quality (Berger and Puettmann 2000; Strong *et al.* 1991). Understory layers of a forest ecosystem help to regulate carbon dynamics and capacity as sources of macro nutrients (nitrogen, phosphorus and potassium) in a boreal forest soil community (Lagerström *et al.* 2013; Mariani *et al.* 2006; Nilsson and Wardle 2005). The herbaceous layer and its component species, coupled with succession stages over time, demonstrates changes in forest plant community dynamics (Gilliam 2007; Nilsson and Wardle 2005).

There are complex interactions among and between plant species within an ecosystem (Pugnaire and Luque 2001). A determinant of heterogeneity of understory species is the influence of the dominant canopy species; their leaf litter physical and chemical values can influence the diversity of understory plant communities (Berger and Puettmann 2000; MacDonald and Fenniak 2007; Lagerström *et al.* 2013). In some instances, other plants act as competitors; and the competitive nature of some plant species, along with other adaptations such as plasticity of reproduction, allelopathy, or fast growth rates, benefits one species at the detriment to others. In other circumstances, interaction of plants may facilitate plant growth among other individuals, of the same or other species (Callaway and Walker 1997; Gomez-Aparicio *et al.* 2004; Treberg and Turkington 2010) or as nurse plants for seedlings (Barbour *et al.* 1987; Schulze *et al.* 2005).

2.1.2 BWBS and ESSF Biogeoclimatic Zones

For ecological and forest management values, B.C. has been divided into 14 zones according to geography, climate, and associated plant species. Two of these are found in the Peace region of northeastern B.C., the Boreal White and Black Spruce (BWBS), and the Engelmann Spruce – Subalpine Fir (ESSF) zones. These zones are further divided into subzones that indicate the typical soil moisture range and climate, and the variant, which indicates plant associations (Pojar *et al.* 1991).

Typical climatic conditions for the BWBS zone include mean annual temperature range between -2.9° C to +2° C. Mean precipitation values for this zone vary between 330 mm and 570 mm, with 35 % to 55 % falling as snow (DeLong *et al.* 1991). In northeastern B.C. on the eastern slopes of the Rocky Mountains, the wet cool (wk) is a dominant subzone, and forests are dominated by lodgepole pine and white spruce (DeLong *et al.* 1991).

Features of the ESSF zone in northeastern B.C. include a mean annual temperature varying between -2° C and +2° C. Temperatures below freezing (0° C) persist for five to seven months per year. Annual precipitation values in this zone vary widely, with some regions receiving 400 mm per year, whilst others receive up to 2200 mm for the same period, with between 50 % and 70 % falling as snow (Coupé *et al.* 1991). The variability in snowfall within the ESSF zone means subzones vary according to precipitation, and the moist very cold (mv) subzone is found in northeastern B.C.

2.2 Natural Gas in Northeastern B.C.

The Peace region is part of the Western Canadian Sedimentary Basin, which spans from northeastern B.C. at its western edge, eastward through much of Alberta, and further through

Saskatchewan and Manitoba (USGS 2013). Some research asserts that petroleum deposits in this basin are among the world's largest hydrocarbon sources, development for which began in the 1950s (Jones 1995; MacKendrick *et al.* 2001; Schneider *et al.* 2003). The BC Ministry of Energy, Mines and Natural Gas figures from 2006 assert that the Western Canada Sedimentary Basin had 52 Tcf (Trillion cubic feet) of natural gas available, as well as 60 Tcf of CBG (Coal Bed Gas). Estimated extraction figures for the south Peace region of BC were around 15,000 Tcf/d (Trillion cubic feet per day) (BC Ministry of Energy, Mines and Natural Gas 2012).

2.3 Disturbances Due to Pipelines

2.3.1 Pipelines

Transportation of natural gas in Canada utilizes truck, rail, and pipeline options. Pipelines are an efficient, if controversial, method of transporting petroleum products from the source to distribution centres and markets (Brito and de Almeida 2009; Ericson 2009; NRC 2013). Natural gas is a difficult product to transport, as its low density in gaseous form is expensive relative to useable product to the end user (Ericson 2009). The need to compress natural gas for most efficient transport requires specialized pipes as it requires storage and transportation under high pressure, and ideally under low temperatures, to maintain a sufficient bulk density that provides an acceptable cost and benefit to the purchaser (Thomas and Dawe 2003).

Construction of pipelines in forest ecosystems involves tree and other vegetation removal to create a right-of-way between fifteen to thirty metres wide (Desserud *et al.* 2010). This is followed by trench digging, when soils are piled according to horizon (A, and B and C horizons, Figure 1). One side of the trench is generally reserved for soil storage, and the other side of the trench is used for vehicle and machinery access. These protocols can have adverse effects on soil physical and chemical properties through soil compaction and mixing of soil horizons, and nutrient loss through leaching when soils are piled for a period of time, and left open to precipitation infiltration (Naeth *et al.* 1987; Shi *et al.* 2014).

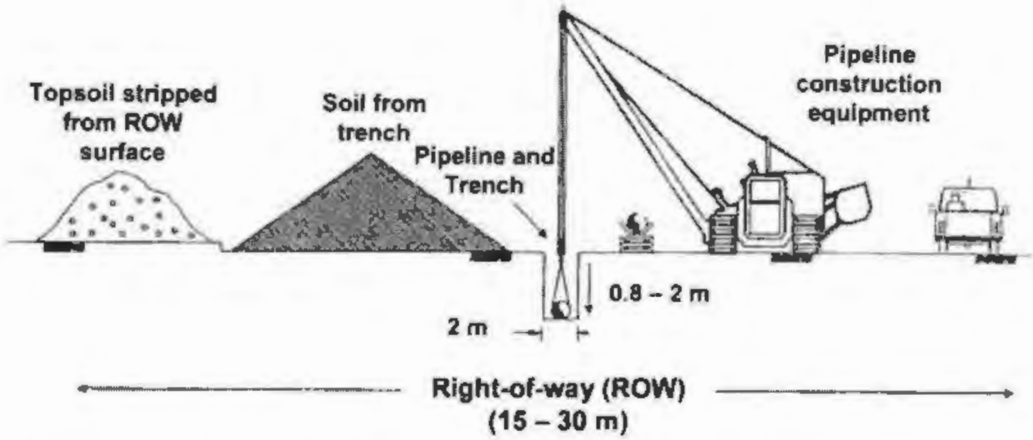


Figure 1. Example of pipeline construction spacing and layout of soil (Desserud *et al.* 2010).

2.3.2 Forest Fragmentation

The installation of natural gas infrastructure in forest ecosystems alters continuity of forest cover (Lee and Boutin 2006). The removal of trees for right-of-way construction may differ from forestry practices that utilize partial cut harvesting, while all vegetation is removed during right-of-way construction (Thorpe and Thomas 2007; Man *et al.* 2008). Boreal forest ecosystems are disturbance based, driven by fire, wind events, or insect outbreaks. Plant species that respond favourably to disturbance thrive in boreal ecosystems (McCullough *et al.* 1998). Natural disturbances facilitate germination of species with serotinous cones, and increase volumes of coarse woody debris, which is not always emulated by human-based disturbances (Schwilk and Ackerly 2001; Schoennagel *et al.* 2003).

2.3.3 Soil Horizon Disturbance

During construction of trenches for installing natural gas pipelines, forest soils undergo some level of disturbance (Prose *et al.* 1987), which includes disturbance of soil horizon layers. Industrial activities may further affect soil structure and water relations through compaction due to seasonal variations in soil strength (Olson and Doherty 2012). In the instance of forest harvesting, the impacts of repeated passes by tree harvest and removal equipment can cause soil compaction in moist soils (Reeves *et al.* 2012; Sutherland 2003). Ground-based timber harvesting for well pad and pipeline construction impacts on soil depends in part on topography and soil texture (Reeves *et al.* 2012). Forest harvest guidelines in B.C. recommend tree harvest should be seasonal, identifying periods when soils may better withstand impacts of heavy machinery used in timber harvest (MacDonald 1999; Petter *et al.* 2009; Reeves *et al.* 2012). Seasonal variances in soil strength are in part due to moisture content, so spring is usually a time when soils are typically wetter, and therefore have less strength, and are often inappropriate times for forest harvest and other industrial activity. Late summer and winter may be preferable for use of heavy machinery when soil compaction can be minimized due to low soil moisture values, and frozen ground in winter (Sutherland 2003). Other complexities arise when constructing sites on or near wetlands, as there may be unfrozen layers under the frost table (Wright *et al.* 2009).

2.3.4 Other Disturbance Repercussions

There are other environmental and social consequences related to pipeline development. On a local scale, human activities can facilitate establishment of invasive plant species through canopy openings, or when vehicles or equipment act as vectors (Cody *et al.* 2000; Byers 2002; Olsen and Doherty 2012). On a landscape scale, there can be consequences for wildlife and fish, noise pollution and air quality concerns, particularly during the construction phase of a pipeline (Van Hinte *et al.* 2007). Pipeline right-of-ways impact forest ecosystems by fragmenting mature forest stands (Nitschke 2008), disrupt caribou migration patterns (Dyer *et al.* 2001), and increase wolf predation of caribou by line-of-sight creation (Latham *et al.* 2011). Social consequences of pipeline development have been associated with decline in social fabric, shrinking productive trapping areas, and lower participation in traditional activities for people in First Nations communities (Angell and Parkins 2011).

2.4 Reclamation of Pipeline Rights-of-Way

2.4.1 Regulatory Context

The regulator of natural gas activities in B.C. is the British Columbia Oil and Gas Commission (BC OGC). Reclamation of gas facilities in B.C. is described as "the process of restoring the natural environment to acceptable condition, as near as reasonable to conditions that existed prior to development" (BC OGC 2011 p 1). Reclamation guidelines for industrially disturbed sites are governed by the BC OGC for issuing reclamation certification. The regulator has requirements for operators that stipulate general vegetative requirements under the "Schedule B Site Reclamation Requirements" (BC OGC 2013) regarding density, species composition and percent cover; Schedule B requirements relate specifically to lands within the Agricultural Land Reserve (ALR). Information about plant species use is not specified in forested lands outside the ALR. The BC OGC stipulates that land be restored to an equivalent condition following pipeline installation; however, there is no minimum replacement depth (MRD) of surface soil on linear disturbances (BC OGC 2013). Topsoil salvage is required, although for soils with A horizons less than 10 centimetres deep, no minimum depth is required in forested lands.

2.4.2 Goals of Reclamation

There are two overarching principles guiding reclamation options for a given site, which include prescriptive planting operations, and natural regeneration strategies. The strategy employed at a given site may be determined by the desired or mandated reclamation outcome, or the capacity of a site to regenerate naturally (Rayfield *et al.* 2005; Gärtner *et al.* 2011; Holl and Aide 2011). A study of a degraded ecosystem examined simple and complex restoration strategies found that moderate complexity of restoration efforts determined plant community recovery (Rayfield *et al.* 2005). The complexity of reclamation strategies may be dependent on site specific conditions, where the level of site degradation and environmental variables correlate with the intensity of site management necessary to promote forest rehabilitation (Stanturf and Madsen 2002; Blanco and Lal 2008; Chazdon 2008).

2.4.3 Plants

When replanting strategies are chosen in a reclamation program, practitioners should decide on the species to employ. Historically, planting programs in reclamation have been haphazard regarding plant types, and forest tree species were used according to silviculture practices and timber values (Kelty 2006; Groninger *et al.* 2007). There has been increasing attention given to emulating native species specific to a disturbed ecosystem. Using native plant species in reclamation helps restore ecosystem functions of a site, and aids in recovery of ecosystem integrity (Chazdon 2008). Identifying key native plant species can be achieved by reference sites, and pre disturbance inventories (Koch 2007). Plant species used in reclamation projects should include mixtures of successional species that include understory and canopy seedlings to enhance species diversity in degraded forest ecosystems (Sayer *et al.* 2004).

2.4.4 Amendments

When soils are disturbed by industrial activities, storage of topsoils during the construction phase can lead to nutrient leaching, and low nutrient values are challenging to successful establishment for either natural revegetation or planted seedlings. Two options for enabling improved microsite conditions for spontaneous regeneration of plants, and better field performance of planted seedlings, include the amendments of fertilizer and unused plant materials such as coarse woody debris (Jacobs and Timmer 2005). Fertilizer amendments are frequently used to increase major nutrients, such as nitrogen, phosphorous, and potassium, to planted tree seedlings for reforestation (Thirukkumaran and Parkinson 2000). Nitrogen, phosphorus and potassium ratios can vary according to ecosystem needs, however a nitrogen component is usually included because of its essential role in plant development (Brady and Weil 2008).

Fallen trees and branches are part of natural processes and plant responses to natural disturbance events in forest ecosystems; this component of a functioning ecosystem can be simulated by deployment of unused plant matter, or coarse woody debris, in forest reclamation. Coarse woody debris (CWD) creates microsites, and enhances soil physical properties and plant seedling establishment in boreal forest stands (Takahashi *et al.* 2000). Coarse woody debris can be used for reclamation purposes and may be a key factor of successful reclamation in forest ecosystems (Brassard and Chen 2008; Vinge and Pyper 2012). Its use in reclamation has been paralleled with its role within intact forest ecosystems for enhancing soil physical properties, and improved plant establishment (Brown and Naeth 2014). To improve site conditions for reclamation, CWD should be left at the harvest site, enhancing nursing environments for young seedlings, stabilizing of soil pH, and mitigating erosion potential (Brown and Naeth 2014; Kappes *et al.* 2007; MacKenzie 2011).

2.4.5 Soil Properties

Soils are key foundations to forests, and soil health is a critical component of forest development (Brady and Weil 2008). Soil properties are indicators of forest ecosystem health; properties such as physical and chemical properties are interrelated, and the interplay between soils and vegetation form a nutrient feedback cycle (Doran and Ziess 2000). Human activities have altered elements of this relationship through intensive forest practices and subsurface disturbances that displace soil horizons (Ballard 2000). Due to industrial disturbance, soil quality and integrity following disturbance can be impacted by industrial development (Piirainen *et al.* 2007; McConkey *et al.* 2012; Reeves *et al.* 2012), and legacy soil quality in turn affects plant growth and survival (Fisher and Binkley 2000; Knoepp *et al.* 2000; Schoenholtz *et al.* 2000). The soil properties affected depends on disturbance type, such as pipeline construction, which involves whole tree harvest, potential removal of litter horizons, and disturbance of A, B, and C horizons in mineral soils, and O horizons in organic soils (Landsburg 1989; Desserud *et al.* 2010). In some cases, disturbance of parent materials can alter the pH of mineral soils if lower and upper substrates are mixed during the disturbance process (Hammermeister *et al.* 2003; McConkey *et al.* 2012).

Mixing of soil horizons during disturbance and in preparation for replanting (Naeth *et al.* 1987; Thiffault *et al.* 2011; Zummo and Friedland 2011) can impact site and soil quality. This disturbance can vary in consequence for the recovery of vegetation, although evidence is sparse (Maynard *et al.* 2014) for either concept. Some research suggests that mixing soils can enhance growing conditions for some plant species such as lodgepole pine, which can access soil nutrients exposed through soil mixing (Ballard 1980; Campbell *et al.* 2006; Thiffault *et al.* 2011).

Soil chemical properties affect the performance of planted seedlings, as well as natural regeneration of a disturbed ecosystem (Jurgensen *et al.* 1997; Schoenholtz *et al.* 2000). Values of soil nutrients such as N, S and P can be altered (Coiffait-Gombault *et al.* 2011) if existing organic matter is lost through whole tree removal and burning of forest floor material (Ballard 2000). In many instances, some nutrients can be made available to plants through disturbance, although nitrogen requires atmospheric or biotic input (Ballard 1980). Litterfall is a significant step in nutrient cycling; nutrients return to the forest floor in organic form, where mineralization makes them available to plants (Huang and Schoenau 1997). A meta-analysis of the removal of harvest residues found a slight decrease in nitrogen, whereas leaving residue showed an increase in total nitrogen in forest soils. Depending on harvest type and plant species, sawlog harvest left more residues on site and increased soil N and soil C, while whole tree removal left little harvest residues, which reduced soil nutrient retention (Johnson and Curtis 2001).

Soil bulk density is an indicator of soil compaction, and is relative to soil class (soil texture). Different thresholds for what determines a compacted soil to the extent it can influence plant growth depends on soil texture and soil moisture; for example, high soil moisture means a fine textured soil is more prone to compaction by human activities (Berli *et al.* 2004; Campbell *et al.* 2008). Soil compaction can have long-term effects on soil productivity, and is attributed to lower growth rates of plants in agricultural and forest soils (Conlin and van den Driessche 1996; Grigal 2000; Spoor 2006). Most effects of heavy equipment on soil bulk density occur when soils are relatively wetter, and within the first few passes over the same area by harvesting and construction equipment (Lovich and Bainbridge, 1999; Lee and Boutin, 2006). Some research has shown high bulk density for a given soil class to be a factor for reduced biomass, reduced root-shoot ratios, and reduced plant survival in lodgepole pine seedlings (Corns 1988), therefore activities should take place when compaction is less likely, such as winter or late summer in cold, dry ecosystems on these soils.

Soil pH refers to acidity or alkalinity of a soil, and it influences the survival and growth of plants, potentially more so during pipeline reclamation. Many plant species have a preferred pH range, and unsuitable pH can affect establishment and growth of some plant species (Hartel, 1999). Industrial disturbance may alter soil pH, for example mixing surface horizons with subsoil material rich in carbonates (Hammermeister *et al.* 2003); but some disturbed forest soils may not always exhibit changes in soil chemical properties due to industrial disturbance (McConkey *et al.* 2012). This may be a site-specific factor, as research regarding pipeline installations found that chemical properties of some soil types are altered differentially by disturbance (Naeth *et al.* 1987).

Soil temperature changes following industrial disturbance due to increased exposure to solar radiation and the condition of surface organic horizons (Stathers and Spittlehouse 1990). Industrial disturbance can affect the range of soil temperature due to whole tree removal (Hayhoe and Tarnocai 1993; Mariani *et al.* 2006). Soil temperatures can impact the regrowth of certain plant species in cold regions such as those found at high elevations and latitudes (McConkey *et al.* 2012). In some ecosystems, increased soil temperature may slightly extend growing seasons at more northern latitudes (Way and Oren 2011). As some plants are more tolerant of wide temperature variances throughout a growing season, the consequences of soil temperature effects on plant growth are site- and species-specific (Hayhoe and Tarnocai 1993; Schulze *et al.* 2005).

Soil moisture is another variable that may be influenced by industrial disturbance. Soil moisture is a critical component of plant growth; it influences species establishment in plant community development and rates of soil respiration (Raich and Tufekcioglu 2000; Ehrenfeld *et al.* 2005). Ground-based industrial activity impacts the water retention and porosity of a soil, therefore the ongoing use of pipeline right-of-ways for maintenance and travel can impact right-of-way soil moisture (Naeth *et al.* 1987; Lovich and Bainbridge, 1999; Lee and Boutin, 2006). Research from northeastern BC (McConkey *et al.* 2012) suggested that treatments applied to soils affected water holding capacity of soils during summer months.

Soil carbon content and soil nutrient availability to plants can be altered due to underground pipeline installation (Soon *et al.* 2000a). Soil nutrients are important to achieving a reliable method for determining effects of substrate disturbance (Schoenholtz *et al.* 2000). Confounding effects of substrate disturbance may occur between physical and chemical properties of disturbed soils (Coiffait-Gombault 2011; Soon *et al.* 2000b; Naeth *et al.* 1987), as soil disturbance can expose minerals and nutrients that would otherwise be unavailable to plant seedlings (Naeth *et al.* 1987; Piirainen *et al.* 2007). In many ecosystems, industrial activities have increased the availability and abundance of nutrients such as nitrogen, but reduced that of other nutrients (Evans and Belnap 1999; Frey *et al.* 2003). In instances where substrate disturbance has altered soil pH, soluble phosphorus can be reduced (Soon *et al.* 2000a).

2.4.6 Topography

Slope is a component of soil phase, defined as a functional unit that varies according to the classification of soil taxa (Agriculture and Agri-Food Canada, 2010). The steepness of a slope, combined with soil texture, determines slope stability when vegetation is removed (Withers 1999; Reubens *et al.* 2007). Mechanical weathering and erosion move topsoil downslope, which can negatively impact plant growth at the upper elevations of a slope and smother seedlings at lower slope positions. Stability of some aggregates has been linked to the susceptibility of topsoil for erosion and is further influenced by particle size and distribution (Barthes and Roose 2002). Aggregate stability determines resistance of topsoil to slaking, which is caused by air that becomes compressed within rapidly wetted soil aggregates. Steeper gradients are subject to increases in overland flow of water, and water stress to plants growing on a slope is greater than areas with little slope. Topography can also influence plant species diversity at a site with moderate to steep slopes (Pareliussen *et al.* 2005; Zinko *et al.* 2005).

Slope aspect determines the amount of sunlight and other environmental factors to which plants and soils are exposed. At high latitudes in B.C., seasonal changes in sunlight mean daily sunlight exposure varies between seventeen hours in June, to six hours in December. Astrom *et al.* (2007) documented that soils on north-facing slopes in the Northern Hemisphere are wetter and cooler than south-facing slope soils, due to a lower amount of solar radiation. Under certain circumstances, even in period of long daylight hours, sun exposure can be minimal. South-facing slopes in North America receive a greater amount of solar radiation than north-facing slopes (Warren II 2010). The soils on south-facing slopes warm faster, and may suffer greater losses of water through evaporation than north-facing slopes. Conversely, as they receive greater amounts of sunlight, plants on south-facing slopes begin annual growth sooner than plants on north facing slopes.

As aspect determines light exposure and moisture retention, different plant species may be present according to their adaptability and suitability to low or high light exposure (Schulze *et al.* 2005). Plant species that respond to high light conditions, such as lodgepole pine, may exhibit stronger growth on south facing slopes at high latitudes. A study from northern B.C. found increased growth rates of lodgepole pine seedlings in response to high light conditions in a boreal forest region (Wright *et al.* 1998), and that light was more strongly correlated to plant growth than regional climatic conditions for lodgepole pine (Wright *et al.* 1998). High light conditions may be a feature of tree harvest where opening a dense forest canopy allows for greater light penetration to the forest floor, and coupled with aspect of a gradient that dictates exposure to sunlight.

High elevation can be limiting to plant growth. Plant species growing at high elevations experience low soil nutrients, moisture deficits which are also related to slope percentage, persistent freezing temperatures for ambient and belowground conditions, and persistent high winds (Körner 1998; Cano *et al.* 2002; Lloyd and Fastie 2002). High elevation mountainous soils are often poorly developed with thin to variable organic layers, which combined with low temperatures, leads to lower rates of nutrient cycling (Rowell 2010).

Erosion includes the transportation and deposition of organic matter and certain soil particle sizes may result when pipeline construction results in changes in topography. In areas subject to high displacement of soil through wind erosion, even sparse vegetation can mitigate some effects of mechanical erosion (Wolfe and Nickling 1993). Coarse woody debris is another mitigation measure for reducing erosion. Its role has been extensively studied in riparian ecosystems (Gregory *et al.* 1991; Lee *et al.* 2004), and has been successfully used for erosion control in upland ecosystems (Bobiec 2002; Vinge and Pyper 2012). Coarse woody debris may be naturally sourced from windthrown trees, from local trees not deemed desirable lumber species, or be placed strategically for structured intervention for forest management (Keddy and Drummond 1996; Robertson and Bowser 1999). Its roles in upland forest ecosystems include erosion control, seedling shelter from mechanical effects like wind, and from biotic effects such as trampling (Brown *et al.* 2003) by wildlife.

3.0 Ojay Study Site

The site for this study was located in the south Peace region of B.C., east of the Rocky Mountain range, approximately 40 km west of the Alberta border and 70 km southeast of Tumbler Ridge B.C. (Figure 2). The pipeline right-of-way was established in 2007 in an area leased by Shell Canada and was part of a natural gas transmission line within the Deep Basin North natural gas reserve of the Western Canadian Sedimentary Basin. The 21 km Ojay pipeline was established by Shell Canada to transmit sweet gas from seven well heads to a collection station in northwestern Alberta (Sherrington, pers. comm. 2012) during the winter of 2007-2008.

The installation of the pipeline included clearing of an 18 m right-of-way in a mature forest stand to facilitate access of equipment for construction and backfill operations. For the construction of the pipeline, one side of the trench was cleared for vehicle and machinery access to the trench for excavation and installation of pipe; and the other side of the trench contained separate mounds of A horizon soils, laid closest to forest edge, and B and C horizons, laid next to the trench. The one exception was the ESSF 4 block, where only the trench area itself was disturbed. Trees in this block were removed at an earlier date for the establishment of a winter industrial access road, and not part of the harvest for the pipeline right-of-way.

Figure 2. Location map of Ojay study site in northeastern British Columbia.

The study area consisted of sampling units, defined for this study as "blocks". The research blocks were established by Shell Canada. Eight blocks in total were established (Table 1), which included four in the BWBS zone and four in the ESSF zone. Blocks were numbered according to slope and aspect positions; number one blocks were established on south-facing slopes, number two at a hill crest, number three on north facing slopes, and number four in wetlands. Forest types at the edge of the right-of-ways were upland coniferous, with lodgepole pine as the dominant canopy species (except the BWBS north-facing block, which was mixedwood), and wetland blocks were lowland coniferous. The ESSF 1 (south-facing) and ESSF 3 (north-facing) blocks had relatively steep slopes, and both mid-slope blocks which were on opposite sides of the same hill.

Slope aspect within the research area varied mostly between north and south, incorporating the direction of the pipeline. There were conditions where for example, BWBS 2, although designated a crest position, had a five percent slope with a west aspect. Blocks ESSF 1 and ESSF 3 were mid-slope sites; ESSF 1 had a south-east aspect and ESSF 3 had a north-east aspect. The two north-facing blocks (BWBS 3 and ESSF 3) were given a CWD amendment, from logs not salvaged or burned, to mitigate erosion potential (Figure 3). The arrangement of logs in the BWBS 3 block was uniform and perpendicular to the slope, and incorporated at a high density. The CWD used in the ESSF 3 block was arranged randomly and employed a much lower density than at the BWBS 3 block (Figure 3).

Figure 3. Coarse woody debris (CWD) applications in the BWBS 3 and ESSF 3 north facing blocks (M. Sherrington photos).

Table 1. Location, elevation, forest type and dominant canopy species at Ojay research blocks.

Zone	Block*	Latitude	Longitude	Elevation (m.a.s.l.)	Forest Type**	Dominant Canopy Species
BWBS	1	54° 43' 58.9"N	120° 11' 14.8"W	1202	Conifer	Lodgepole pine
BWBS	2	54° 44' 0.2"N	120° 11' 12.8"W	1226	Conifer	Lodgepole pine
BWBS	3	54° 44' 2.1"N	120° 11' 10.1"W	1212	Mixedwood	Lodgepole pine, balsam poplar
BWBS	4	54° 45' 23.2"N	120° 12' 59.7"W	1225	Conifer	Black spruce
ESSF	1	54° 42' 57" N	120° 6' 8.0"W	1350	Conifer	Lodgepole pine
ESSF	2	54° 43' 21.6"N	120° 5' 26.2"W	1369	Conifer	Lodgepole pine
ESSF	3	54° 42' 26.1"N	120° 6' 57.2"W	1360	Conifer	Lodgepole pine
ESSF	4	54° 43' 25.8"N	120° 5' 17.7"W	1262	Conifer	Black spruce, tamarack

BWBS = Boreal White Black Spruce

ESSF = Engelmann Spruce Subalpine Fir

*Block designation:

1 – South-facing block

2 – Crest block

3 – North-facing block with CWD amendment

4 – Wetland block

**Forest type (Penner 2008):

Conifer: > 80 % softwood

Mixedwood: 26-75% softwood

All research blocks were adjacent to mature forest stands (Table 1). At the BWBS 1 and 2 blocks, and the ESSF upland blocks, upland conifer stands were dominated by lodgepole pine. The BWBS 3 block was a mixedwood stand, and the wetland blocks were conifer dominated.

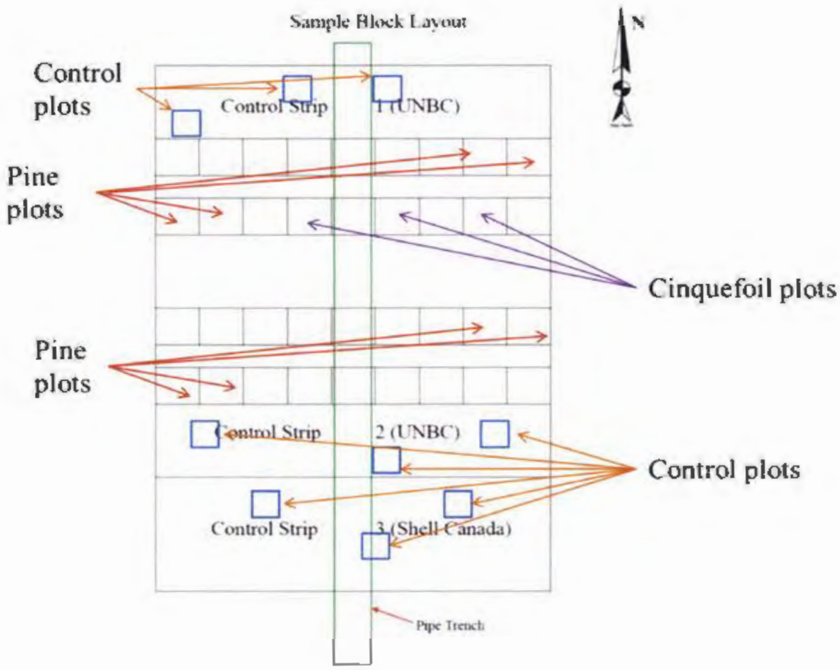


Figure 4. Sample block layout showing pipe trench (green rectangular box) and plot locations within block boundaries.

Permanent plots were marked for the study, based on the original plot sizes determined in the layout established by Shell Canada and Reclaimit Ltd. (Figure 4), marked by wood stakes. Block sizes were 18 m x 37 m, except in the BWBS 4 block, where the encroachment of a winter access road reduced the block width to 15 m. Within the block boundaries, four strips were arranged for plant trials, each was 2 m wide and the width of the block boundary (18 m, except BWBS 4). Within the strips, 2 m x 2 m (4 m^2) permanent plots were established, however, the area over the pipe trench, the width of a digging bucket (914 mm) (Pedram and Sherrington, pers. comm. 2012) was sporadically planted with shrub and forb species not considered in this study. In this study, control strips, which consisted of unplanted areas, were established by Shell

Canada. In 2012, unplanted control plots were created within the previously established control strips to determine extent of natural regeneration of plant species for the study period.

In the summer of 2010, Reclaimit Ltd. planted 4 tree species, 11 shrub species, and 2 forb species (see Appendix 2 for species list and planting numbers) in the plots. Plant seedlings were one-year-old at time of planting, and were propagated by Sylvan Vale Nursery in Black Creek, B.C. Species selected for planting were based on soil moisture regime tolerance, and tree seedlings were planted as far as practicable from the pipe trench. Fertilizer pouches (N:P:K ratio 25:0:0) were added to holes dug for lodgepole pine seedlings in upland blocks at the time of planting; shrub and forb seedlings did not receive fertilizer treatment at planting.

Treatments for the purpose of this study were defined as plots planted with either lodgepole pine (*Pinus contorta*) or shrubby cinquefoil (*Dasiphora fruticosa*). Upland blocks had eight pine plots and three cinquefoil plots each; planting densities for pine ranged between 10-20 individuals, and between 50-100 individuals for cinquefoil within each plot. Wetland blocks had four pine plots per block, BWBS 4 had two cinquefoil plots, and ESSF 4 had three cinquefoil plots. Some plant species were common to all eight blocks (e.g. lodgepole pine and shrubby cinquefoil), while others (e.g., white spruce (*Picea glauca*), black spruce (*Picea mariana*), mountain avens (*Dryas octopetala*) and tamarack (*Larix laricina*)) were only present in blocks associated with preferred soil moisture regimes for the species.

4.0 Soil Properties and Topographic Features on a Reclaimed Pipeline Right-Of-Way in Northeastern British Columbia

Abstract

Soil properties can determine the establishment and growth of plants, and are often altered by industrial development. The objective of this study was to determine soil properties and topography on a reclaimed natural gas pipeline right-of-way in northeastern B.C. Soil properties analysed included *in situ* moisture content, cation exchange capacity (CEC) (and exchangeable cations), particle size distribution, total C, and major nutrient content including total N, S, and available P. Separate soil samples were taken in June 2013 and analysed for pH and bulk density. Analyses showed variable soil moisture, nutrients, and cation exchange capacity between the upland blocks. The soil properties analysed in this study were influenced by presence or absence of organic horizons in mineral soils; soil nutrients, soil C, and CEC were high in organic wetland soils. This study found variability in soil properties related to slope aspect, which could impact reclamation decisions in northeastern B.C.

4.1 Introduction

The resource extraction industry in western Canada has become the backbone of Canada's economy. Natural gas reserves in northeastern B.C. contributed to approximately 27% of total marketable Canadian natural gas production in 2014 (NEB 2015). A number of alternatives exist for the transport of natural gas, and transport via underground pipelines is a common option. As more pipelines are proposed and constructed, there is a need to understand the impacts of right-of-way clearing and soil horizon disturbance on forest soils, to provide background information for developing refined strategies for the reclamation of pipeline rights-of-way.

Right-of-way clearing for a pipeline involves whole tree harvest, and soil horizon disturbance through trench construction (Desserud *et al.* 2010). Following pipe installation, the trenches are backfilled with stored soils, and prepared for reclamation. Mechanical site preparation is the practice of recontouring a harvested area for planting, using heavy equipment to decompact soils, remove unwanted woody debris, and sometimes to create microsites to facilitate plant establishment (Bulmer and Krzic 2003; Löf *et al.* 2012). It is commonly used to promote faster regrowth of forest stands (Schmidt *et al.* 1996). Some research has found that increasing severity (windrowing and burning) and complexity of site preparation techniques (fertilization plus tree seedling planting) was associated with improved performance of conifers in reforestation of industrially disturbed sites in interior B.C., and Sudbury, Ontario (Haeussler *et al.* 1999; Rayfield *et al.* 2005).

Although the impacts on soils by forest practices are generally well understood, the repercussions to soils from underground pipeline installation in northeastern B.C. are less well known. Pipeline infrastructure installations change soil horizons, can remove organic matter and may alter slope stability in mountainous terrain (Naeth *et al.* 1987; Piirainen *et al.* 2007;

Thiffault *et al.* 2011; Zummo and Friedland 2011; McConkey *et al.* 2012; Olson and Doherty 2012; Reeves *et al.* 2012), therefore it is critical to better encapsulate the effects of linear forest fragmentation, whole tree removal, and soil horizon disturbance related to pipeline installations.

This study was conducted to understand the impacts to soils, plant communities, and field performance of planted seedlings by right-of-way clearing and pipe trench construction for natural gas transfer infrastructure. The objective of this study was to examine soil chemical and physical properties, and topographic features present on a reclaimed natural gas pipeline right-of-way in northeastern B.C. This primary objective was to improve knowledge of what roles soils play in plant community recovery and plant growth and survival at a pipeline right-of-way reclamation project in the Boreal White and Black Spruce wet cool biogeoclimatic subzone (DeLong *et al.* 1991) and Engelmann Spruce – Subalpine Fir moist very cold biogeoclimatic subzone (Coupé *et al.* 1991) in northeastern B.C.

4.2 Materials and Methods

4.2.1 Study Site and Experimental Design

The study site was located in the south Peace region of northeastern B.C., on the eastern slopes of the Rocky Mountain range, 40 km west of the Alberta border. The study area was subject to logging for right-of-way establishment in 2007, except the area including the ESSF 4 block, which was harvested in 2004 for winter road construction. The pipeline right-of-way was established in 2007 at an asset leased by Shell Canada (see Chapter 3 for site details). The dominant soil type in the research area was the Luvisolic order (Luvisols and Gray Luvisols were noted at the site). Site soil moisture and nutrient regimes were originally reported by Shell Canada environmental staff in 2007, and confirmed by the UNBC research team (Table 2) in 2012.

Table 2. Soil moisture and nutrient regimes for each block.

Biogeoclimatic Zone	Block no.*	Soil Moisture	Soil Nutrient Regime
BWBS	1	Mesic	Medium
BWBS	2	Submesic	Poor-Medium
BWBS	3	Subhygric	Rich
BWBS	4	Hydric	Medium
ESSF	1	Submesic	Low
ESSF	2	Subxeric	Poor
ESSF	3	Submesic	Medium-Rich
ESSF	4	Hydric	Medium

BWBS- Boreal White and Black Spruce
ESSF- Engelmann Spruce – Subalpine Fir
*Block description
1 – South-facing block
2 – Crest block
3 – North-facing block with CWD amendment
4 – Wetland block

4.2.2 Sampling and Data Collection

At each of the six upland blocks, eight pine plots and three cinquefoil plots were established in 2010 (see Chapter 3 for more details on block establishment by Shell Canada). In the two wetland blocks, four pine plots were created; in BWBS 4, two cinquefoil plots were created, and three cinquefoil plots were made in ESSF 4. In this study, treatment referred to unplanted controls, and plots planted with lodgepole pine (fertilized at planting in upland blocks), and shrubby cinquefoil.

A total of three hundred soil samples (two samples were taken from each plot for control, pine and cinquefoil plots) were taken for chemical and physical properties in August 2012, and consolidated for each plot (n = 150, see Table 3). The samples were stored in a cooler at 4°C, then air dried at ambient air temperatures, and re-weighed (450 g each). The mineral soil samples were sifted through a 2 mm sieve to remove large particles and organic debris. These samples were used for pH, particle size analysis, nitrogen, carbon, sulphur, phosphorus, and cation exchange capacity (CEC). Core samples were taken for bulk density calculations. All results were expressed on an oven-dry equivalent basis.

Table 3. Number of soil samples taken from each plot, block and biogeoclimatic zone in 2012.

		Treatments			
Biogeoclimatic zone	Block	Control	Pine	Cinquefoil	Soil samples per block
BWBS	1	9	8	3	20
BWBS	2	9	8	3	20
BWBS	3	9	8	3	20
BWBS	4	9	3*	2**	14
ESSF	1	9	8	3	20
ESSF	2	9	8	3	20
ESSF	3	9	8	3	20
ESSF	4	9	4	3	16
				Total	150

BWBS – Boreal White and Black Spruce
ESSF – Engelmann Spruce – Subalpine Fir
* One pine plot disregarded due to human interference in BWBS 4
** Two plots planted with cinquefoil in BWBS 4

4.2.2.1 Soil Pits

Soil pits were dug in 2013 to understand the physical features found within the area disturbed for right-of-way clearance and construction. The components of soils considered in this study were adapted from the Land Management handbook 25 (BC MoFR and MoE 2010) Soil Descriptions chapter. One soil pit was dug on the right-of-way at each block, and one pit was dug in the forest adjacent to the right-of-way block. Data were recorded for organic horizons, humus type, soil horizon depth (A, B, and C), soil texture, and drainage.

4.2.2.2 Soil Moisture

Volumetric soil moisture readings were taken in 2012 and 2013 growing seasons. Readings were taken with a portable Delta T soil moisture reader, using a Theta Probe (type ML2x), at the surface of mineral soil on the pipeline to a depth of 5 cm (probe length). Two readings were taken from each plot, and an average of the two readings was reported. Fluctuations in wetland water tables were documented by way of steel welding rods installed along a transect in the BWBS 4 and ESSF 4 wetland blocks to track seasonal fluctuations in moisture levels (Bridgham *et al.* 1991; Silins and Rothwell 1999). The range of oxidation observed along the welding rods was measured, and measurements were used to determine the range of fluctuation of water tables in the wetland blocks over the growing season.

In February 2013, snow depth in all blocks was measured to understand the potential that snow contributes to soil moisture in early summer. Two rows were laid out in 25 m length transects, spaced 5 m inside from block boundaries. Snow depth was measured with a snow probe every 1 m along each transect ($n = 50$ per block), along with recordings as to whether the soil beneath the snow pack was frozen or unfrozen.

4.2.2.3 Soil Temperature

Soil temperature was taken in the second year of field sampling. Eight HOBO dataloggers (one datalogger per block) were installed outside the block boundaries. One temperature probe was installed at a depth of 10 cm on the pipeline right-of-way within the block boundary and one probe was installed at a depth of 10 cm in the adjacent forest. Readings were logged every two hours from June 2013 until October 2013.

4.2.2.4 Bulk Density

One hundred and twenty-eight samples were taken at 0 cm (core depth to 6 cm) with a slide hammer ($r = 2.7$ cm, $h = 6$ cm, volume = 137.47 cm^3) at random points in plots within the block boundaries for control, lodgepole pine, and shrubby cinquefoil plots, and in random points on right-of-ways and the adjacent forest. For each block, eight samples were taken on pipeline, and eight were taken from within the forest. One hundred and three samples were used for bulk density calculations; twenty-five samples were disregarded as they could not be accurately identified. These samples were oven dried at 70°C for four days, and re-weighed. Bulk density of the samples was calculated using the equation: dry weight (g) / soil volume (cm^3).

4.2.2.5 Soil pH

Soil pH was determined using distilled water (dH_2O) following methods described by Kalra and Maynard (1991) in a laboratory at UNBC. For mineral samples, 25 g soil was combined with 50 ml dH_2O to achieve a 1:2 soil to dH_2O ratio. For organic samples, 5 g soil was diluted with 50 ml dH_2O for a 1:10 ratio. Samples were stirred intermittently for 30 minutes, and then allowed to stand for a further 30 minutes. Readings were taken using a Thermo ORION 550 A pH meter, which was calibrated at 4.0, 7.0, and 10.0 pH levels.

4.2.2.6 Additional Soil Properties, Cation Exchange Capacity, and Texture

Samples from each plot were sent to the B.C. Ministry of Environment Chemistry analysis laboratories in Victoria B.C., where the analyses for soil C, soil nutrients, cation exchange capacity (CEC) and particle size analysis were performed. See Appendix 1 for methods applied for each analysis.

4.2.2.7 Topography

Topographic properties of each research block were provided in ground inspection forms by Shell Canada, and were confirmed by the UNBC research team in 2012. Aspect was verified with a Suunto™ MC-2 NH mirror compass (2012 declination = 18° 14.76'E, NRC 2016), slope was confirmed using a Suunto™ PM5/360PC clinometer, and elevation was determined by a Garmin™ Dakota®20 global positioning system (GPS).

4.2.3 Data Analysis

In this chapter, the data were not subjected to standard tests for normality or ANOVAs, as the purpose was to characterize soil properties in the research blocks. The results described trends at the blocks. Statistical relationships between soil properties and plants are presented in chapters 5 and 6. Results for soil moisture, bulk density, macronutrients (N, S, P), soil C and CEC were separated between wetlands and uplands. Topographic variables were reported as whole numbers. Soil properties were subjected to descriptive statistics, analysed with STATA® 13.1 (StataCorp LP, College Station, Texas, USA), means and standard errors were reported in the results.

4.3. Results

Soil pit descriptions are shown for uplands only, as data was not available from the BWBS wetland block. Results of major nutrients (total N, total S, and available P), soil total C, effective CEC, soil moisture, and bulk density were separated between uplands and lowlands due to marked differences in values. Soil class (texture) was recorded in upland blocks only, and results of the BWBS 3 block were disregarded as the high organic matter content nullified the usefulness of particle size results.

4.3.1 Soil Pit Descriptions

Soil physical properties were compared between the right-of-way and the forest to determine effects of human disturbance. Organic layers (Table 4) for upland soils were shallow on the right-of-way with the exception of BWBS 3, and in a few instances, there was no organic layer present. The BWBS 3 block had the moder humus form on the right-of-way and in the forest, whereas the BWBS 2 block had mor humus form on the right-of-way and moder humus form in the forest.

Table 4. Soil pit organic layer features for right-of-way and forest upland blocks.

		Soil Organic Layer Depth (cm)				Humus Form	
		Right-of-way		Forest		Right-of-way	Forest
Zone	Block	Maximum	Minimum	Maximum	Minimum		
BWBS	1	0	0	9	7	N/A	Mor
	2	1	0	5	3	Mor	Moder
	3	20	15	36	20	Moder	Moder
ESSF	1	0	0	12	9	N/A	Mor
	2	0	0	3	1	N/A	Mor
	3	1	0	12	9	Mor	Mor

Humus forms:
Moder: Some incorporation of litter into mineral soil
Mor: Mat of partly decomposed litter, not well incorporated in mineral soil
N/A: Not Applicable

Humus types from right-of-way samples were mostly fibric, although there was evidence of decomposition in humus at the BWBS 3 block, where some mesic material was noted. At the forest pits, humus types were fibric at the BWBS 1 block, while there was mesic material in the crest and north facing sites. The humus type was fibric at all upland forest pits in the ESSF zone.

Mineral layers in upland blocks varied considerably (Table 5). There were three instances (BWBS 1, BWBS 2, and ESSF 2) where the A horizon was not discernable from the B horizon. Where the A horizon was present, it was deeper than the A horizon depths observed in the forest pits. At BWBS 3, the A horizon depth maximum on the right-of-way was greater than intact forest soil by 1 cm. At ESSF 1, the A horizon maximum on the right-of-way was similar to the intact forest soil (difference was 1 cm), and at ESSF 3, the right-of-way A horizon exceeded the forest soil A horizon by up to 22 cm. Depths at which C horizons were observed varied between blocks, however, highest points of C horizons were observed at a greater depth in the north-facing blocks in each zone than either the south-facing or crest position blocks (Table 5).

Table 5. Soil mineral layers for right-of-way and forest sample pits in upland blocks.

			Soil Mineral Layers							
			Depth (cm) (Right-of-way)				Depth (cm) (Forest)			
Zone	Block	Layer	Suffix*	Extent	Maximum thickness	Minimum thickness	Suffix	Extent	Maximum thickness	Minimum thickness
BWBS	1	A	-		not discernable		h	0-9	9	7
		B	p	0-28	28	22	t	10-40	30	20
		C	k	29+	N/A	N/A	k	40 +	N/A	N/A
	2	A	-		not discernable		h	0-15	15	10
		B	p	0-36	36	32	m	16-46	34	30
		C	k	36 +	N/A	N/A	k	47+	N/A	N/A
	3	A	h	0-16	16	12	h	0-15	15	12
		B	hf	17-71	46	41	g	15-85	75	70
		C	k	71 +	N/A	N/A	k	85 +	N/A	N/A
ESSF	1	A	he	0-19	19	12	h	0-18	18	16
		B	m	19-51	37	29	m	19-68	48	40
		C	g	51 +	N/A	N/A	k	68 +	N/A	N/A
	2	A	-		not discernable		h	0-15	15	9
		B	m	0-35	35	33	g	16-48	36	27
		C	k	35 +	N/A	N/A	k	48 +	N/A	N/A
	3	A	h	0-40	40	35	h	0-18	18	9
		B	m	41-83	42	35	g	19-47	33	29
		C	k	83 +	N/A	N/A	k	47+	N/A	N/A

* Suffixes as defined in Soil Classification Working Group (1998):
g: grey colours or prominent mottling
h: enriched with organic matter
he: natural eluviation with grey shades and sometimes platy structure
hf: more than 5% organic C
k: presence of carbonate
m: slightly altered by hydrolysis, oxidation, or solution
p: altered by human activities including pipeline construction
t: illuvial horizon enriched with silicate clay

Drainage of the upland sites varied according to slope position. Drainage classes were very well drained in the south-facing blocks and the BWBS 2 block; the ESSF 2 block was rapidly drained. The drainage class for north-facing blocks were moderately well drained in the ESSF 3 block, and imperfectly drained in the BWBS 3 block. Soil pits dug on the right-of-way and in the adjacent forest had ground seep at approximately 60 cm (Figure 5) in the BWBS 3 block.

Figure 5. BWBS 3 (north-facing block) right-of-way soil pit showing seep at approximately 60 cm depth.

4.3.2 Soil Moisture

Soil moisture in upland sites varied between biogeoclimatic zones, slope position, and aspect (Figure 6). Moisture values in upland blocks were highest in north-facing blocks in each zone, and lowest in crest position blocks in 2012. There was more soil moisture variability in 2013; in the BWBS zone, lowest mean values were recorded in the BWBS 1 block, while the BWBS 2 block had the lowest mean moisture content in the ESSF zone. In the wetland blocks, soil moisture values in BWBS 4 were higher in 2013, while ESSF 4 block content was higher in 2012 (Figure 7). Results from oxidation range on welding rods in the wetland blocks found a 9.5 cm average moisture fluctuation for the 2013 growing season.

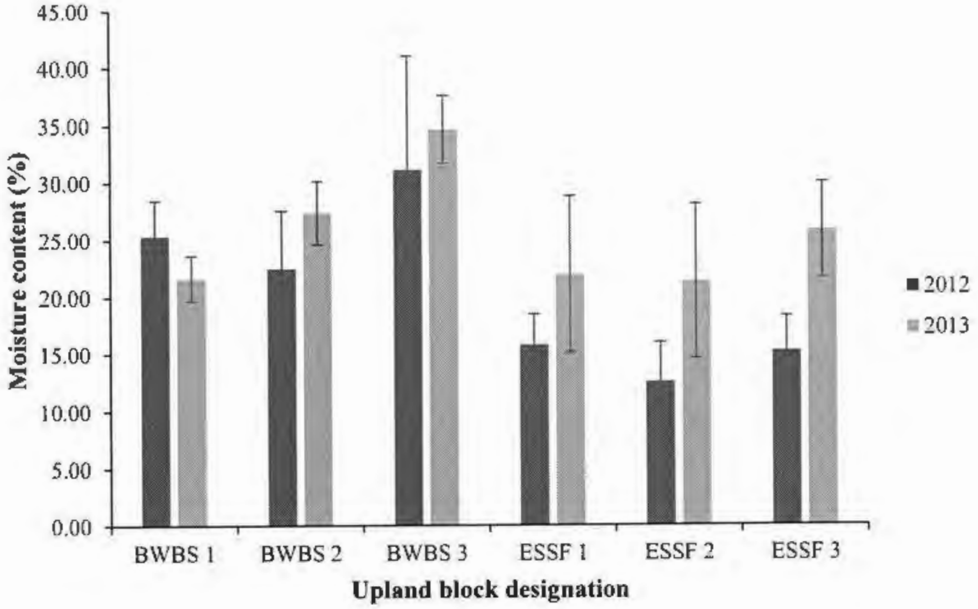


Figure 6. Mean soil moisture with standard error in upland blocks for 2012 and 2013. n = 20 per block.

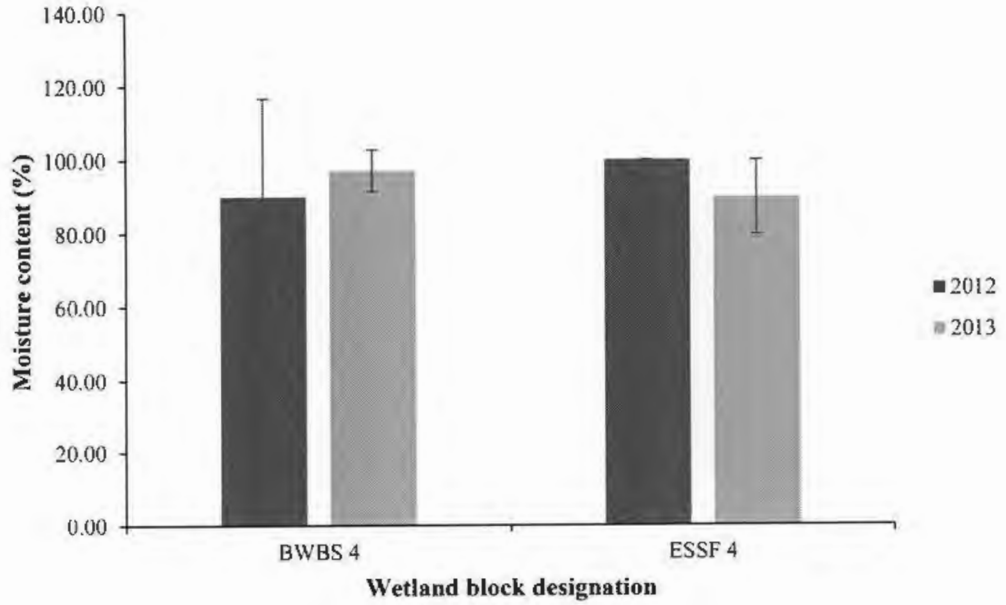


Figure 7. Mean soil moisture with standard error in wetland blocks for 2012 and 2013 growing seasons. n = 14 for BWBS 4; n = 16 for ESSF 4.

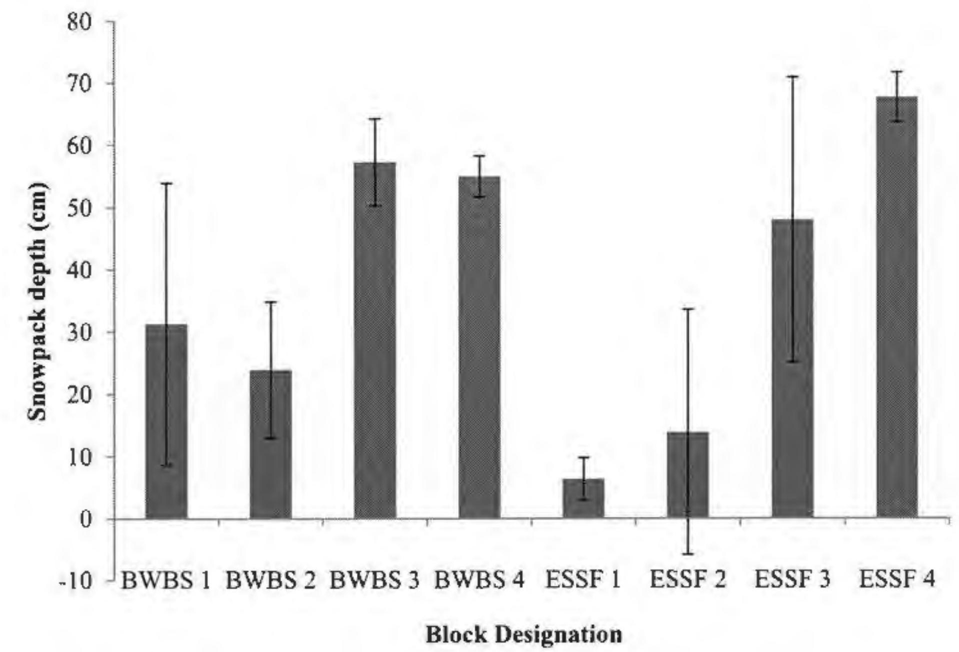


Figure 8. Mean snowpack depth with standard error, winter 2012-2013. (n = 50 per block).

Snowpack measurements taken in February 2013 showed greatest depths at the ESSF 4 block, with an average of 67.7 cm between two transects (Figure 8). For the BWBS 4 block, average snow depth was 54.9 cm. ESSF blocks 1 and 2 had the least snow cover, the ESSF 1 block held 6.3 cm of average snow cover, and ESSF 2 held 13.8 cm of snow. Soils were frozen in south-facing, crest, and north-facing blocks in both biogeoclimatic zones. In the wetland blocks, there was a frost layer underneath the snow, however, the soils below the frost layer were unfrozen. There were no weather stations in close proximity to the study site to make comparisons at the block or biogeoclimatic zone level.

4.3.3 Soil Bulk Density

Bulk density values were variable at upland blocks (Figure 9) and the differences between right-of-way and forest bulk density values were inconsistent. Bulk density within the BWBS 1 block was the highest (1.33 g cm^{-3}) in the BWBS biogeoclimatic zone, and greatest of all upland blocks, while the ESSF 3 block right-of-way bulk density value (1.24 g cm^{-3}) was highest for the ESSF zone. Bulk density was slightly higher on the right-of-way for all BWBS blocks. This pattern for bulk density was not replicated in the ESSF zone, as samples from the right-of-way had lower bulk density values than those taken from the forest in the ESSF 1 and 2 blocks, however the ESSF 3 block showed higher bulk density on the right-of-way than for samples taken from the forest.

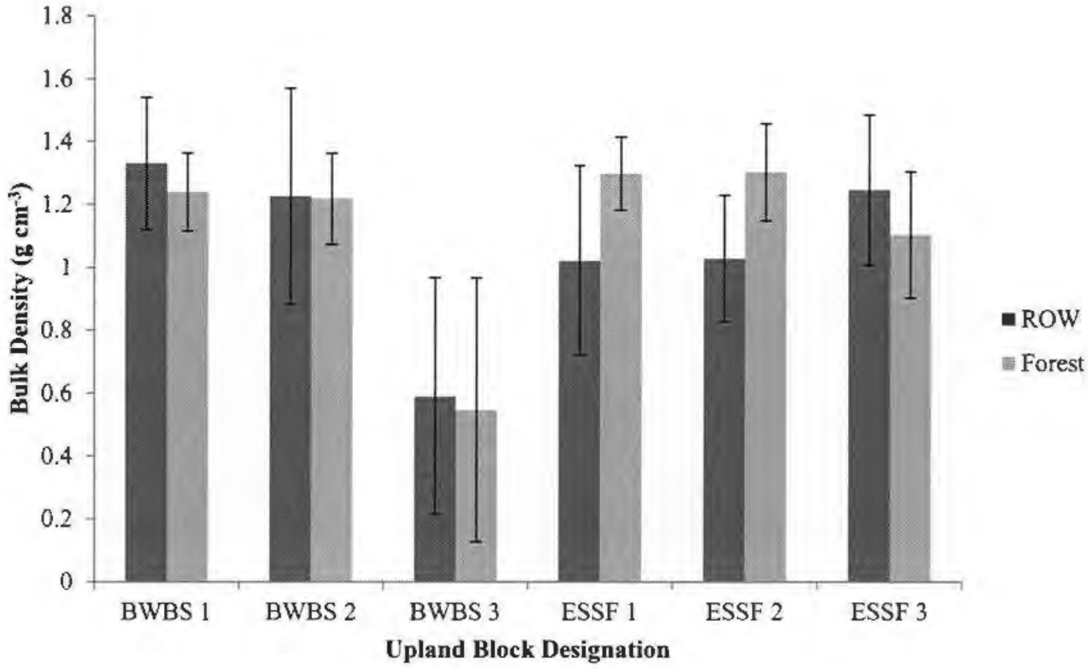


Figure 9. Mean and standard error of bulk density on pipeline right-of-way (ROW) and forest in upland blocks. Bulk density was taken for the 0 – 15 cm range of mineral soils in upland blocks (BWBS 1-3, ESSF 1-3). BWBS 1 n = 15, BWBS 2 n = 12, BWBS 3 n = 5, ESSF 1 n = 15, ESSF 2 n = 15, ESSF 3 n = 16.

There was high variability of bulk density within the BWBS 3 block for both the right-of-way and forest, but otherwise the error of the means showed higher variability for right-of-way samples than for forest samples in upland blocks. Bulk density values for the BWBS 4 block were higher on the right-of-way (0.14 g cm^{-3}) than the forest (0.067 g cm^{-3}), while the forest bulk density (0.22 g cm^{-3}) was higher than the right-of-way (0.16 g cm^{-3}) bulk density for ESSF 4 block (Figure 10).

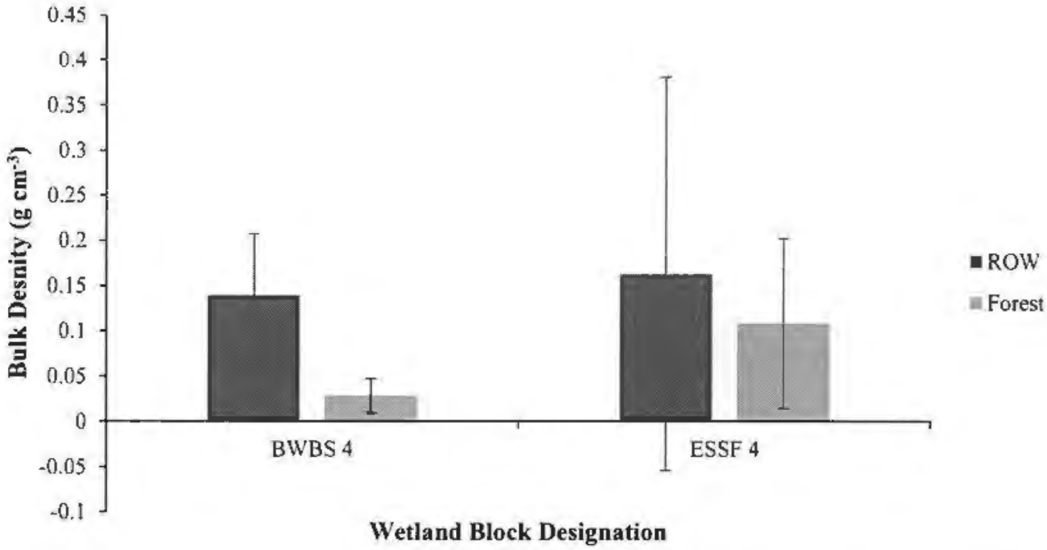


Figure 10. Mean and standard error of bulk density on pipeline right-of-way and forest in wetland blocks. Bulk density was taken for the 0 – 15 cm range in organic horizons for wetland blocks (BWBS 4, ESSF 4). BWBS 4 n = 11, ESSF 4 n = 14.

4.3.4 Soil Temperature

Soil temperature taken within growing seasons at 10 cm depth (Figure 11) showed that BWBS upland blocks had greatest mean temperature at the BWBS 1 block (14.7 °C ± 1.2 °C) and lowest in the BWBS 3 block (13.3 °C ± 1.4 °C). In the ESSF zone, soil temperature average was greatest in the ESSF 1 block (13.8 °C ± 2.1°C) and lowest in the ESSF 3 block (11.5 °C ± 1.2 °C). The highest mean temperatures in the ESSF zone were recorded in the ESSF 4 block (14.7 °C ± 1.0 °C), whereas the lowest temperature averages in the BWBS zone were observed in the BWBS 4 block (13.3 °C ± 1.0 °C).

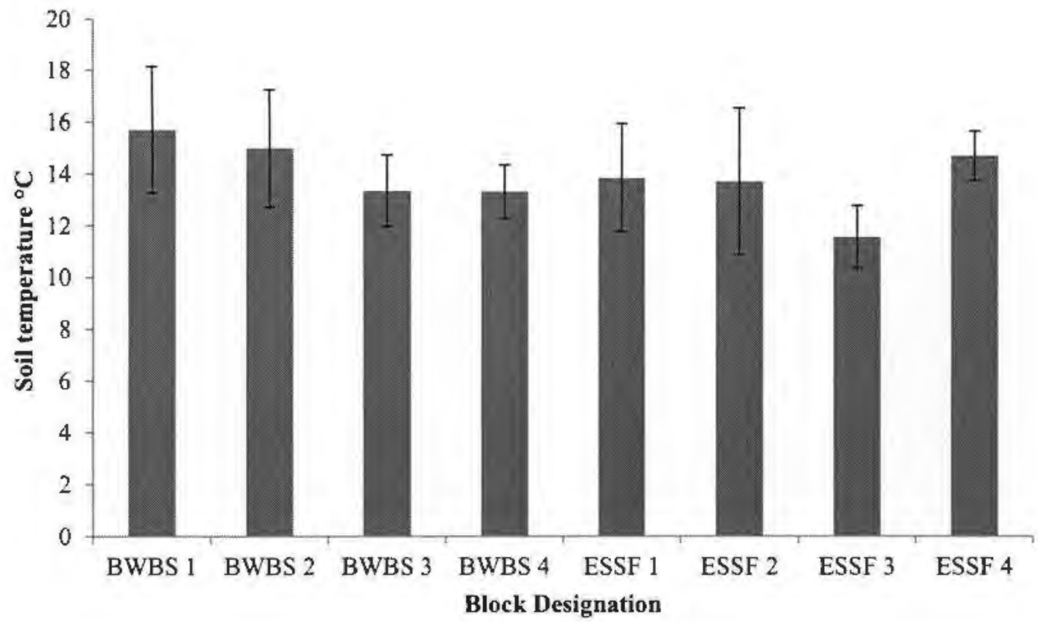


Figure 11. Mean soil temperature in all blocks in 2013. Temperature taken in the 0-10 cm depth range. Averages are for the growing season (June-August 2013), n = 20 each for upland blocks (BWBS 1-3; ESSF 1-3. For wetland blocks: BWBS 4 n = 15, ESSF 4 n = 16).

4.3.5 Soil Texture

There was variable particle size distribution between upland blocks from the particle size analysis conducted on mineral soils (Table 6). Soil class extrapolated from particle percentages (sand, silt, and clay) was consistent in BWBS 1 for the control, pine, and cinquefoil plots. All other upland block mineral soils varied between silty loam and loam soils between control, pine, and cinquefoil plots, however there was no consistent pattern of particle size distribution. Samples from BWBS 3 were considered invalid due to a greater than 10 % total C content. The soil classes were more consistent between crest and north-facing blocks, while south-facing block soil class was of medium texture (loam) in the BWBS zone, while the ESSF zone was fine to medium (silty loam – loam).

Table 6. Particle size (means and standard errors reported in parentheses) for sand, silt and clay with associated soil class for upland blocks. For each upland block, n = 9 for control plots, n = 8 for pine plots, and n = 3 for cinquefoil plots.

Block	Treatment	Sand % (±)	Silt % (±)	Clay % (±)	Soil Class*
BWBS 1	Control	42.51 (4.18)	41.34 (2.45)	16.15 (3.95)	L
	Pine	42.81 (2.74)	41.39 (2.10)	15.80 (1.64)	L
	Cinquefoil	43.98 (1.45)	40.74 (1.40)	15.28 (0.05)	L
BWBS 2	Control	38.40 (4.08)	45.30 (6.03)	16.30 (4.21)	SiL
	Pine	35.98 (4.82)	47.00 (5.27)	17.01 (1.32)	SiL/L
	Cinquefoil	32.09 (0.91)	55.21 (0.91)	12.69 (0.00)	SiL
BWBS 3	Control		* results invalid		N/A
	Pine		* results invalid		N/A
	Cinquefoil		* results invalid		N/A
ESSF 1	Control	37.41 (2.92)	50.01 (2.12)	12.58 (1.43)	SiL
	Pine	38.31 (3.49)	49.44 (4.32)	12.25 (1.93)	SiL
	Cinquefoil	40.59 (2.17)	46.68 (1.58)	12.73 (1.32)	L
ESSF 2	Control	37.19 (3.27)	48.47 (1.90)	14.34 (2.31)	SiL/L
	Pine	36.80 (3.47)	50.48 (4.18)	12.72 (2.78)	SiL
	Cinquefoil	33.89 (1.25)	52.13 (1.26)	13.99 (0.00)	SiL
ESSF 3	Control	42.35 (6.79)	41.18 (5.63)	16.47 (2.07)	L
	Pine	32.43 (5.12)	50.44 (4.24)	17.13 (2.43)	SiL
	Cinquefoil	33.02 (2.83)	49.49 (1.39)	17.49 (1.44)	SiL/L

* Soil class:
L- Loam
SiL- Silty Loam
SiL/L- Silty Loam/Loam
N/A- Not Applicable

4.3.6 Soil pH

Soil pH levels were higher (5.92 - 7.41, ± 0.24 - 0.83) at BWBS upland sites than ESSF upland sites (4.62 - 4.96, ± 0.27 - 0.48) (Figure 12). Comparatively, average pH in upland blocks was highest per zone for the south-facing blocks (BWBS 1 and ESSF 1), BWBS 3 exhibited the most acidic conditions for all treatments in the BWBS zone, while in ESSF upland blocks, pH was consistently higher in cinquefoil plots than either pine or control plots. Wetland block pH levels were 6.13 ± 0.28 for the BWBS 4 block, and 6.63 ± 0.27 for the ESSF 4 block (Figure 12), and pH was higher in pine plots than in cinquefoil or control plots.

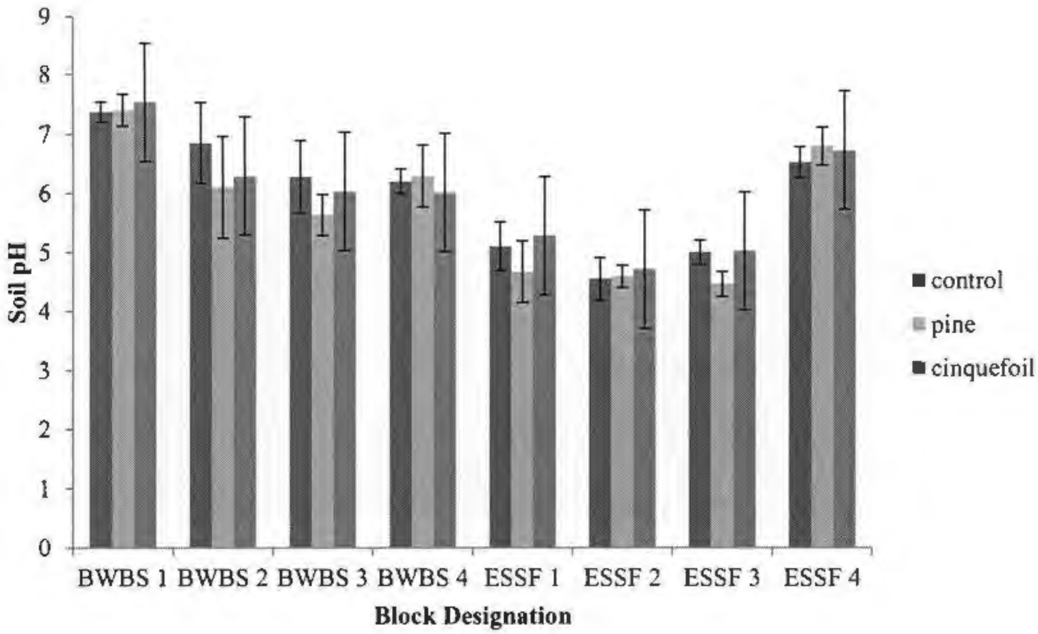


Figure 12. Mean and standard error of soil pH for control, pine, and cinquefoil plots. For each upland block, control n = 9, pine n = 8, cinquefoil n = 3. For wetland blocks, BWBS 4, control n = 9, pine n = 3, cinquefoil n = 2; ESSF 4, control n = 9, pine n = 4, cinquefoil n = 3.

4.3.7 Cation Exchange Capacity

Soil CEC in upland blocks exhibited wide variations within BWBS zone blocks, but more consistent values in the ESSF upland blocks (Figure 13 and Table 7). BWBS 3 CEC values were much higher than those observed for BWBS 1 and 2. In BWBS 1 and BWBS 2, plus the ESSF upland blocks, CEC in the control plots was higher than in pine and cinquefoil plots. This was not reflected in BWBS 3 results.

CEC values for wetland blocks (Figure 14 and

Table 8 8) were similar between the BWBS (control: 171.20 cmol (+) $Kg^{-1} \pm 19.88$, pine: 140.57 cmol (+) $Kg^{-1} \pm 8.37$, cinquefoil: 186.32 cmol (+) $Kg^{-1} \pm 19.69$) and ESSF (control: 181.25 cmol (+) $Kg^{-1} \pm 22.72$, pine: 168.46 cmol (+) $Kg^{-1} \pm 20.30$, cinquefoil: 138.44 cmol (+) $Kg^{-1} \pm 44.96$) blocks although greater variability was noted in the ESSF cinquefoil samples.

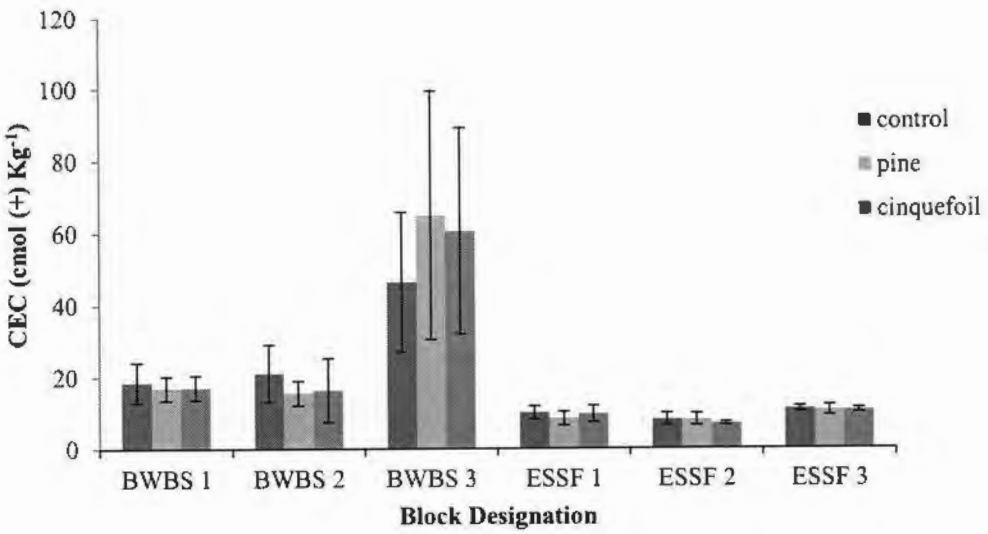


Figure 13. Mean and standard error of CEC (cmol (+) Kg^{-1}) with standard error of upland blocks. For each upland block, control n = 9, pine n = 8, cinquefoil n = 3.

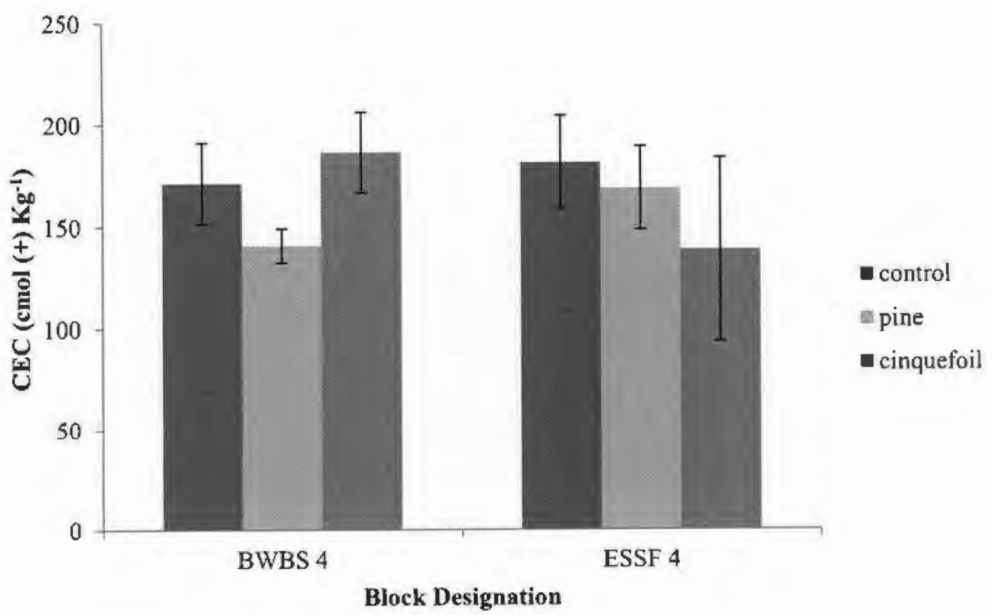


Figure 14. Mean and standard error of CEC (cmol (+) Kg^{-1}) in wetland blocks. In BWBS 4, control n = 9 pine n = 3 cinquefoil n = 2; in ESSF 4, control n = 9, pine n = 4, cinquefoil n = 3.

Table 7. Mean CEC and exchangeable cations (Al, Ca, Fe, K, Mg, Mn, Na) and standard error (±) (Cmol (+) Kg^{-1}) of soil in upland blocks. For each upland block, Control = 9, Pine n = 8, Cinquefoil n = 3.

Block	Treatment	Al	Ca	Fe	K	Mg	Mn	Na	CEC
BWBS 1	Control	0.04 (0.08)	16.6 (5.04)	0.01 (0.02)	0.13 (0.03)	1.69 (0.55)	0.004 (0.001)	0.02 (0.01)	**18.47 (5.57)**
	Pine	0.06 (0.08)	15.16 (2.87)	0.02 (0.02)	0.12 (0.02)	1.43 (0.55)	0.01 (0.00)	0.02 (0.01)	**16.80 (3.38)**
	Cinquefoil	0.15 (0.13)	15.49 (3.13)	0.04 (0.04)	0.13 (0.02)	1.21 (0.17)	0.00 (0.00)	0.01 (0.01)	**17.03 (3.40)**
BWBS 2	Control	0.10 (0.15)	18.36 (7.00)	0.02 (0.03)	0.13 (0.03)	2.36 (1.21)	0.01 (0.01)	0.01 (0.00)	**21.00 (8.00)**
	Pine	0.17 (0.15)	13.00 (3.64)	0.03 (0.02)	0.14 (0.03)	2.12 (0.64)	0.03 (0.03)	0.02 (0.00)	**15.51 (3.43)**
	Cinquefoil	0.22 (0.14)	13.81 (8.09)	0.04 (0.01)	0.13 (0.05)	2.10 (1.07)	0.02 (0.02)	0.02 (0.00)	**16.31 (8.92)**
BWBS 3	Control	0.05 (0.06)	38.81 (16.31)	0.01 (0.02)	0.27 (0.08)	7.16 (3.11)	0.06 (0.04)	0.03 (0.01)	**46.38 (19.40)**
	Pine	0.03 (0.05)	54.25 (30.18)	0.01 (0.01)	0.36 (0.13)	10.12 (4.27)	0.09 (0.03)	0.04 (0.01)	**64.90 (34.49)**
	Cinquefoil	0.11 (0.09)	51.09 (25.16)	0.02 (0.02)	0.33 (0.19)	8.94 (3.36)	0.07 (0.04)	0.03 (0.01)	**60.594 (28.65)**
ESSF 1	Control	1.10 (0.95)	5.55 (1.49)	0.07 (0.06)	0.15 (0.02)	3.02 (1.19)	0.04 (0.03)	0.08 (0.15)	**10.01 (1.83)**
	Pine	1.98 (1.21)	4.15 (1.85)	0.10 (0.06)	0.15 (0.02)	1.98 (1.31)	0.03 (0.02)	0.02 (0.01)	**8.42 (1.95)**
	Cinquefoil	0.54 (0.39)	5.54 (1.66)	0.04 (0.01)	0.14 (0.02)	3.33 (1.00)	0.03 (0.01)	0.02 (0.00)	**9.63 (2.29)**
ESSF 2	Control	2.40 (0.99)	3.92 (1.46)	0.11 (0.08)	0.20 (0.07)	1.41 (0.58)	0.06 (0.05)	0.02 (0.01)	**8.12 (1.68)**
	Pine	2.15 (0.85)	4.06 (1.70)	0.06 (0.02)	0.20 (0.05)	1.39 (0.54)	0.07 (0.03)	0.11 (0.25)	**8.04 (1.70)**
	Cinquefoil	2.52 (0.39)	3.00 (0.22)	0.07 (0.03)	0.19 (0.03)	1.03 (0.08)	0.05 (0.01)	0.02 (0.00)	**6.88 (0.44)**
ESSF 3	Control	0.61 (0.25)	7.39 (0.68)	0.02 (0.01)	0.24 (0.06)	2.67 (0.45)	0.05 (0.03)	0.02 (0.00)	**11.00 (0.74)**
	Pine	2.04 (0.76)	6.10 (1.53)	0.04 (0.02)	0.26 (0.05)	2.01 (0.49)	0.11 (0.14)	0.01 (0.00)	**10.57 (1.44)**
	Cinquefoil	0.95 (0.65)	6.88 (0.81)	0.02 (0.01)	0.28 (0.06)	2.39 (0.45)	0.05 (0.01)	0.01 (0.00)	**10.58 (0.67)**

Table 8. Means and standard error (±) of exchangeable cations (Al, Ca, Fe, K, Mg, Mn, Na) and effective CEC (Cmol (+) Kg^{-1}) of soil in wetland blocks. For wetland blocks, BWBS 4: Control = 9, Pine n = 3, Cinquefoil n = 2; ESSF 4: Control n = 9, Pine n = 4, Cinquefoil n = 3.

Block	Treatment	Al	Ca	Fe	K	Mg	Mn	Na	CEC
BWBS 4	Control	0.02 (0.00)	153.15 (18.79)	< 0.00 (0.00)	0.54 (0.20)	16.88 (1.62)	0.46 (0.30)	0.15 (0.06)	**171.20 (19.88)**
	Pine	0.03 (0.00)	124.16 (7.82)	< 0.00 (0.00)	0.61 (0.10)	15.11 (0.85)	0.48 (0.10)	0.17 (0.06)	**140.57 (8.37)**
	Cinquefoil	0.02 (0.00)	168.35 (17.60)	< 0.00 (0.00)	0.43 (0.11)	17.27 (1.92)	0.15 (0.03)	0.11 (0.04)	**186.32 (22.72)**
ESSF 4	Control	0.03 (0.02)	162.36 (20.49)	< 0.00 (0.00)	0.35 (0.16)	18.15 (2.46)	0.12 (0.09)	0.25 (0.10)	**181.25 (22.72)**
	Pine	0.05 (0.05)	147.54 (18.89)	< 0.00 (0.01)	0.38 (0.05)	20.07 (1.51)	0.10 (0.01)	0.32 (0.11)	**168.46 (20.30)**
	Cinquefoil	0.04 (0.04)	121.42 (41.86)	< 0.00 (0.01)	0.29 (0.18)	16.41 (3.34)	0.11 (0.06)	0.18 (0.03)	**138.44 (44.96)**

4.3.8 Macronutrients

Total soil N was higher at wetland sites than upland sites (Table 9 and Table 10). Nitrogen values in the BWBS 1 and 2 blocks control plots (BWBS 1: 0.115 %, ± 0.039 %, BWBS 2: 0.142 %, ± 0.058 %) in the BWBS zone were higher than for pine (BWBS 1: 0.113 %, ± 0.041 %, BWBS 2: 0.132 %, ± 0.039 %) and cinquefoil (BWBS 1: 0.110 %, ± 0.029 %, BWBS 2: 0.119 %, ± 0.055 %) plots. In contrast, the BWBS 3 block control plots had the lowest N percentage compared to planted plots. At the ESSF 1 and 2 blocks, control plots had the highest mean N values, while the pine plots returned the highest N values in the ESSF north-facing block. In wetland blockss, the N concentration in BWBS 4 control plots (1.99 %, ± 0.33 %) was slightly lower than in ESSF 4 control plots (2.13 %, ± 0.43 %).

Table 9. Means and standard error (expressed in parentheses) of major nutrients (nitrogen, sulphur, phosphorous and potassium) and soil carbon in upland blocks (n = 20 each block).

Block	Treatment	Total N % (±)	Total C % (±)	Total S % (±)	Avail. P mg Kg^{-1} (±)
BWBS 1	Control	0.115 (0.039)	3.92 (0.45)	0.013 (0.005)	1.24 (1.20)
	Pine	0.113 (0.041)	4.11 (1.05)	0.011 (0.007)	1.13 (1.13)
	Cinquefoil	0.110 (0.029)	3.79 (0.43)	0.010 (0.003)	1.29 (1.54)
BWBS 2	Control	0.142 (0.058)	4.52 (2.13)	0.018 (0.009)	7.11 (4.28)
	Pine	0.132 (0.039)	4.18 (1.27)	0.019 (0.007)	14.01 (9.73)
	Cinquefoil	0.119 (0.055)	3.89 (2.17)	0.016 (0.009)	17.21 (6.15)
BWBS 3	Control	0.564 (0.322)	13.02 (7.48)	0.048 (0.015)	2.81 (1.34)
	Pine	1.092 (0.739)	23.04 (14.06)	0.194 (0.231)	3.90 (1.62)
	Cinquefoil	0.902 (0.689)	20.87 (17.00)	0.096 (0.060)	3.28 (1.87)
ESSF 1	Control	0.146 (0.024)	3.90 (0.96)	0.017 (0.002)	20.77 (4.47)
	Pine	0.133 (0.025)	3.54 (1.01)	0.016 (0.004)	25.45 (12.71)
	Cinquefoil	0.130 (0.034)	3.57 (1.30)	0.017 (0.005)	17.39 (1.01)
ESSF 2	Control	0.162 (0.094)	4.27 (3.40)	0.023 (0.013)	22.77 (8.93)
	Pine	0.157 (0.058)	4.03 (1.99)	0.026 (0.008)	48.51 (32.28)
	Cinquefoil	0.114 (0.004)	2.50 (0.09)	0.018 (0.003)	24.51 (2.45)
ESSF 3	Control	0.196 (0.022)	2.46 (0.78)	0.083 (0.029)	11.75 (3.68)
	Pine	0.234 (0.072)	3.30 (1.19)	0.102 (0.026)	14.26 (8.03)
	Cinquefoil	0.189 (0.019)	2.78 (0.06)	0.113 (0.040)	14.71 (3.67)

Most upland sites had comparable values of total C, with the exception of the BWBS 3 block (Table 9). In the BWBS 1 and 2 blocks in the BWBS zone, cinquefoil plots had the lowest total C, while the control plots had the lowest mean total C in BWBS 3. There was no consistency by treatment for mean C values in the ESSF upland blocks. Total carbon was high in hydric soils in both zones (Table 10). Total C in the pine plots was lower than the control or cinquefoil plots, and lowest C values in the ESSF 4 block were observed in the cinquefoil plots.

Table 10. Mean and standard error (expressed in parentheses) of major nutrients (nitrogen, sulphur, phosphorous and potassium) and soil carbon in wetland blocks all treatments (BWBS 4 n = 15, ESSF 4 n = 16).

Block	Treatment	Total N % (±)	Total C % (±)	Total S % (±)	Avail. P mg Kg^{-1} (±)
BWBS 4	Control	2.00 (0.33)	48.75 (6.00)	0.262 (0.048)	3.38 (1.24)
	Pine	1.75 (0.71)	40.81 (9.86)	0.200 (0.058)	4.73 (1.41)
	Cinquefoil	1.91 (0.18)	48.74 (3.87)	0.303 (0.016)	1.68 (0.37)
ESSF 4	Control	2.13 (0.43)	43.86 (5.17)	0.570 (0.294)	2.84 (2.39)
	Pine	1.66 (0.30)	44.94 (1.66)	0.339 (0.097)	4.40 (2.96)
	Cinquefoil	1.43 (0.63)	39.13 (7.95)	0.399 (0.324)	4.04 (3.19)

Total S was lower at upland blocks for both BWBS and ESSF zones than at wetland blocks (Table 9 and Table 10). For upland sites, the north-facing blocks (ESSF 3 and BWBS 3) had higher values than crest and south-facing slope blocks. At BWBS 3, S percentage was highest for pine plots and lowest in the control plots. At the ESSF 3 block, highest values were observed at cinquefoil plots and lowest in the control plots. Wetland total S was highest in the cinquefoil plots in both BWBS and ESSF 4 blocks; lowest values were seen in the pine plots at the BWBS 4 block, while the control plots had the lowest mean S values in the ESSF 4 block.

Available P values in mineral soils were higher in the upland ESSF blocks than the BWBS blocks (Table 9). For the BWBS upland blocks, cinquefoil had the highest amount of available P in the BWBS 1 and 2 blocks, while the BWBS 3 block values were highest in the pine plots. In the ESSF 1and 2 blocks, available P was higher in pine (29.40 mg Kg^{-1} ± 17.47 mg Kg^{-1}) plots, however in ESSF 3, higher P values were found in the cinquefoil plots than for either control or

Figure 15. ESSF 3 (north-facing block) showing slope failure on left and right sites of right-of-way.

4.4 Discussion

Soil properties observed at the research blocks were variable. Properties were related to slope aspect of each block, and surrounding forest canopy was related to soil quality. The incorporation of CWD was beneficial (see Chapter 3 for block design and CWD use) when applied in high density and situated in close proximity to a mixedwood stand.

4.4.1 BWBS biogeoclimatic zone

Upland soil properties in the BWBS zone were variable and were related to organic matter and forest type. The BWBS 1 and 2 blocks in this zone were similar in most of the soil properties analysed in this study. The BWBS 1 block observed relatively higher soil temperatures, bulk density, and moisture values (2013 only). The precipitation and wind experienced at this block may have contributed to variability in soil moisture content, which has been linked in other research (Chen *et al.* 1999). The BWBS 2 block had higher nutrients, was more acidic, and had finer soil texture. The higher soil temperatures observed at the BWBS 1 block in this study were validated by other studies regarding soil temperature on south-facing slopes in the northern hemisphere (Hayhoe and Tarnocai 1993; Schulze *et al.* 2005; Way and Oren 2011). The soil texture difference between the BWBS 1 and 2 blocks implies that the coarser soil particles may have moved downslope, which has been observed previously in research that examined soil particle size and topography (Ampontuah *et al.* 2006). The soil moisture observations in this study were similar to other work involving changes in soil moisture by topography (Western *et al.* 2004).

The BWBS 3 block was adjacent to a mixedwood stand, and had a high density of CWD which, along with the organic matter, may have contributed to the low mean temperature values for the BWBS zone. The influence of proximity to a mixedwood stand along with high density of CWD influenced other soil properties, as increased depth of OM has been shown to be correlated with lower soil temperature and moisture, and translocation of C from leaf litter to soils (Kasischke and Johnstone 2005; Uselman *et al.* 2007). High carbon in this block could be attributed to CWD amendment that potentially buffered winds and allowed for settling of leaf litter. There is also the potential that some leaf litter was not removed during pipeline construction, however decomposition was not considered in this study. High soil organic matter content at BWBS 3 also influenced soil bulk density, as values were lower for right-of-way and forest samples in this block than for other BWBS upland blocks.

Organic matter at the BWBS 3 block was much higher than the BWBS 1 and 2 blocks. The high organic matter in BWBS 3 contributed to higher total organic carbon, soil nitrogen and CEC values. The higher nutrient values may be due in part to the proximity of this block to a mixedwood stand, and the annual senescence from deciduous trees has been correlated with improving soil nutrients in forest soils (Bartels and Chen 2010) and the CWD density in the BWBS 3 block may have allowed for improved leaf litter retention, which is supported by other research that correlated CWD with higher litter retention and soil nutrients at the local scale (Kappes *et al.* 2007).

Soil moisture values in the BWBS 4 block were more variable in 2012 than 2013. High total carbon percentage in this block was consistent with other findings (Fissore *et al.* 2009) of total carbon found in peat soils. The BWBS 4 block returned the lowest soil temperature values in the BWBS zone, which is contrary to the accepted relationship between soil moisture and its ability to retain heat (Al-Kayssi *et al.* 1990).

4.4.2 ESSF biogeoclimatic zone

Snow cover measurements showed variability between and within blocks. Exposure to wind was likely a factor that contributed to snow depth results for the ESSF 1 and 2 blocks, which has been demonstrated in environments with prevalent winds (Hiemstra *et al.* 2002). The variability of snow pack inferred that rainfall was the precipitation likely to contribute to soil moisture values during the growing season. Soil moisture was higher in 2013 than 2012, suggesting higher average rainfall in the 2013 growing season.

Soil bulk density in the ESSF upland blocks exhibited lower values for the ESSF 1 and 2 blocks than the ESSF 3 block for the right-of-way. The bulk density values for the forest were high at the ESSF 1 and 2 blocks, and the lowest value observed was in the ESSF 3 block. All bulk density values fell within the suggested ideal range (< 1.40 g cm^3) for the loam and silty loam soil classes found in the ESSF zone (Daddow and Warrington 1983; Zhao *et al.* 2010).

Soil temperature was higher in the ESSF 1 and 2 blocks than in the ESSF 3 block; the most likely reasons were due to the aspect of the ESSF 3 block combined with mature forest canopy influences on direct solar radiation, as these factors influence the temperature potential of soils at northern latitudes in the northern hemisphere (Stathers and Spittlehouse 1990; Astrom *et al.* 2007; Warren II 2010).

Soil nutrients were variable between blocks, although total N and total S were higher in the ESSF 3 block. As the forest type did not differ between blocks, and as the ESSF 1 block did not have higher nutrient values than the ESSF 2 block, wind may have influenced the movement of these nutrients, however this could not be quantified. There was evidence of slash burning along the right-of-way at the ESSF 1 block, which has been correlated with volatilization of N and S (Ballard 2000).

The ESSF 2 block had higher amounts of available P than the mid-slope blocks, although the mid-slope blocks were on the same hill as the ESSF 2 block. One likely reason was that the A and B soil horizons were shallower at the ESSF 2 block than the ESSF 1 or 3 blocks, and the available P was potentially sourced from the parent materials, and therefore closer to the surface in the ESSF 2 block as a result of soil horizon disturbance during trench construction. The data from the ESSF 2 block showed a higher amount of available P in the pine plots than either the control or cinquefoil plots. This was the only block in which high variability between treatments was observed.

The ESSF 4 block was previously harvested in 2004 for a winter road construction, and was not harvested for the right-of-way construction in 2007-2008 (see Chapter 3 for site description). Therefore, this block was disturbed only for the trench digging and pipe installation. The ESSF 4 block had adequate major nutrient values, and high CEC. It also had the highest average mean temperature of all blocks within the ESSF zone, which is consistent with other findings of this relationship (Davidson *et al.* 1998), although this relationship can have confounding seasonal variability. High CEC values were consistent with the organic matter content of the wetland block, and high total carbon percentage in the wetland block was consistent with other findings (Fissore *et al.* 2009) of total carbon found in peat soils.

In both biogeoclimatic zones, the 1 and 2 right-of-way blocks had low or no humus layers, and low amounts of total carbon. The ESSF 3 block also showed low carbon values although there was CWD amendment. The BWBS 3 block had much higher carbon values, along with high nitrogen. The placement of CWD in this block was denser than at the ESSF 3 block, however the BWBS 3 block was adjacent to a mixedwood stand, whereas the ESSF 3 was adjacent to a pure conifer stand. Soil pits dug both on the right-of-way and in the forest noted differences in A horizon depth, and mixing of horizons in mineral soils. The differences between the right-of-way and the forest suggest that current right-of-way construction practices may alter A and B horizons, and remove organic matter, which contribute to total carbon and soil nitrogen losses (Prescott 2002).

4.5 Conclusion

The research was conducted to understand the potential impacts to soil chemical and physical properties of industrial activities in mountainous areas of northeastern B.C. The results showed that there were differences in soil organic layers and horizon integrity between a pipeline right-of-way and a mature forest stand. Soil carbon and soil nutrient values varied between upland blocks, and CEC was lower in the ESSF upland blocks than the BWBS upland blocks, likely as a result of low on no leaf litter, and wind effects to litter accumulation, and in the case of available P, parent material differences.

There were differences related to presence and depth of organic layers between the right-of-way and intact forest soils. Soil property observations in this study noted significant differences in values between BWBS and ESSF upland blocks. South facing blocks had higher mean temperatures for upland blocks in both biogeoclimatic zones. In the ESSF zone however, the ESSF 4 block had highest observed temperature in comparison to upland blocks in the ESSF zone. There was variable particle size distribution in upland mineral soils. Upland soil pH was higher in samples from the BWBS zone, indicating more acidic conditions in the ESSF block soils likely due to geology, dominant canopy species and climate variations.

The observations of variability between blocks in values of soil carbon, soil nutrients and CEC support retention of organic layers and CWD in mixedwood stands in future reclamation projects in northeastern B.C. The differences in soil moisture content between the BWBS and ESSF upland blocks means industry and reclamation practitioners could consider using appropriate plant species according to soil moisture conditions by biogeoclimatic zone. Other amendments or site preparation techniques could be considered in pure conifer stands where organic horizons have not been reserved, are acidic, or have inadequate soil nutrients, and where prevailing winds may affect plant establishment and field performance.

5.0 Plant Species Diversity on a Reclaimed Natural Gas Pipeline Right-of-Way in Northeastern British Columbia

Abstract

Plant species diversity is an indicator of site health in boreal forest ecosystems. Industrial disturbances including natural gas pipeline rights-of-way affect the exposure of understory plants and forest soils to potentially adverse growing conditions through tree harvest and substrate disturbance. The objective of the study was to determine plant species diversity on a reclaimed natural gas pipeline in northeastern B.C. Presence and abundance of plant species were recorded for unplanted controls, planted lodgepole pine (*Pinus contorta* var. *latifolia*) and planted shrubby cinquefoil (*Dasiphora fruticosa*) research plots. Diversity was calculated with the Shannon Diversity Index. Species diversity was variable at upland blocks in the Boreal White and Black Spruce and Engelmann Spruce – Subalpine Fir biogeoclimatic zones; lowest values were calculated in the crest blocks, and highest values were calculated in wetland blocks. Relatively low diversity in upland sites may warrant rethinking of plant species used in reclamation projects.

5.1 Introduction

Boreal forests are disturbance-based ecosystems. Human activities, such as natural gas extraction and transportation, are additive disturbances. The responses of boreal ecosystems to industrial activities may not replicate responses to natural disturbances (e.g. fire, insect and disease outbreak, wind damage). More recent human activities such as forestry and other resource (coal, oil and gas, etc.) development have added to the disturbance footprint, and often replace natural disturbance regimes, due to forest and infrastructure asset management. Further, industrial disturbances contribute to soil compaction, increased soil bulk density, poor aeration, altered moisture drainage and nutrient leaching (Smith *et al.* 1999). These and other compounding factors can affect plant biodiversity (Maestre 2004). Plant species diversity is a culmination of two components, including the number of individuals of a species (abundance), and the number of different species (richness) found within a specified area (Whittaker 1972; Huston 1979).

There is an increasing need to better understand the role of natural regeneration of the herbaceous layer of forests, in addition to regeneration of tree species (Roberts 2004). Two types of colonizing understory plant species are invaders, which utilize wind as a vector for seed dispersal, and evaders, which rely on existing seed banks in a disturbed setting (Nguyen-Xuan *et al.* 2000; MacDonald *et al.* 2012). Invader plant species, different from invasive plant species, utilize specific conditions (e.g. disturbance) to propagate in a site, and can spread quickly (Lieffers and MacDonald 1993). Adding to this complexity is the dominance of some plant species in areas of low diversity, compared to that of communities with high species diversity (Grubb 1977). An area of disturbance in a single patch basis may also impact the likelihood of germination from existing seed banks in boreal forest soils. Greene *et al.* (1999) postulate that existing soil seed banks in boreal forests may be inadequate to be a significant source of germinants due to low seed productivity and poor germination rates of seeds in intact forest floors.

Information about the regeneration of plant species in the Peace region of northeastern B.C. is fragmentary. The topographic and climatic challenges to plant community regeneration at high elevations, and substrate disturbances that compromise or remove soil horizons and availability of nutrients are poorly understood. To improve boreal forest ecosystem responses to industrial activities, it is important to understand how quickly seed banks respond to open forest canopies, increased soil temperatures, more variable soil moisture, and nutrient availability.

The objective of this study was to determine plant species diversity on a reclaimed natural gas pipeline right-of-way in northeastern B.C. The research was conducted to address the issue of plant species richness and abundance observed on a reclaimed pipeline right-of-way in a boreal forest ecosystem altered by industrial activities. This would fill a knowledge gap regarding plant community recovery in the Boreal White and Black Spruce wet cool biogeoclimatic subzone (DeLong *et al.* 1991) and Engelmann Spruce – Subalpine Fir moist very cold biogeoclimatic subzone (Coupé *et al.* 1991) in northeastern B.C.

5.2 Materials and Methods

5.2.1 Study Site and Experimental Design

The study sites were located in the northeastern region of B.C., east of the Rocky Mountain range, and about 40km west of the Alberta border. The site was established in 2007 within the operations area of Shell Canada (See Chapter 3 for detailed site information). In this study, control referred to unplanted plots within the study blocks, and treatments referred to the plots planted with lodgepole pine or shrubby cinquefoil.

An unplanted control strip was established by Shell Canada, and unplanted control plots within the control strips were created by the UNBC research team. Each block had three strips, and three control plots of 1 m x 1 m were randomly assigned along each strip. Each strip was labeled as 1, 2 or 3 within each block, numbers increasing from a north-south orientation, each plot was labeled A, B, C from a left to right orientation. Limitations exist for the small plot size (Brummer *et al.* 1994), but still provide useful inventory measures for natural regeneration of early successional plant species, as increasing plot size can be inconsistent in reducing variance between grass species, and otherwise may distort diversity values (Brummer *et al.* 1994; Zdenka and Milan 2006).

5.2.2 Sampling and Data Collection

In July and August 2012 and July 2013, all plant species that appeared within individual plot boundaries were documented. Square (1 m x 1 m for controls, and 2 m x 2 m for pine and cinquefoil plots) boundary frames were used for determining counts, and individuals were excluded when more than 50% of the plant diameter at ground level was outside the plot frame (Figure 16). For this study, n was the count of individuals observed within the plots. The numbers of each plant species observed within each plot were counted, which addressed the species richness present inside the blocks. The numbers of individuals for each species were also recorded, which accounted for species abundance.

Figure 16. Data collection for species diversity, showing square for inclusion/exclusion of plants.

Within the treatments, species were grouped into plant types, which included trees, shrubs, herbs and graminoids. A separate "other" group was created for mosses, lichens, and species where the writing was illegible or the species was not identifiable. In this study, two diversity calculations were performed, one for natural regeneration only, and one which included planted lodgepole pine and shrubby cinquefoil. In the Results and Discussion, the natural regeneration only was used to illustrate diversity (see Appendix 3 for species richness, abundance and diversity values with planted species included).

The Shannon Diversity Index (H') was used to determine species diversity within research plots. This index combines the diversity and abundance of species within the plot area. The equation used was:

$$H' = -\sum_{i=1}^{n} pi \ln pi$$

where *H'* was the Shannon Index (Spellerberg and Fedor, 2003), *n* was number of species, and *pi* was the percentage cover of the *i*th species. The Shannon Diversity Index expresses species diversity as a unitless number; lower numbers indicate low levels of diversity, and higher numbers reflect higher species diversity. Values for species diversity can indicate where natural regeneration is a plausible reclamation strategy, and where more intensive reclamation strategies are critical for establishing a diverse plant community.

5.2.3 Data Analysis

The independent variables, recorded in percentages, included soil moisture, slope, total nitrogen, carbon and sulphur, and available phosphorus, plus pH, bulk density, elevation, and presence of an organic horizon (See chapter 4 for detailed results of soil properties). Species richness was an independent variable where species abundance was the outcome variable, and species abundance was used as an independent variable where species richness was the outcome variable. This was done to understand the potential for abundance of a species to affect the number of species (species richness) found within the plots, and if the number of species has an effect on the abundance of a particular plant species.

A Shapiro-Wilk test for normality was performed to validate the species diversity data for normal distribution, and the α was set at 0.05. An ANOVA was performed to determine if species diversity was significantly different between zones and blocks. Where significant differences were shown, a Tukey's test was conducted to determine where significant differences were located. Where the differences between means were significant, a chart was created with mean and standard error, and a letter value was applied according to the Tukey group in STATA. The first mean was given the letter "a", and where differences were discovered in the analysis, a letter “b” was applied. Variables with the same letter (“a”, or “ab”) were not considered statistically significant at $\alpha = 0.05$.

A step-wise regression was initially proposed to analyse the data, however, many collinearity problems emerged in the analysis results, so a hierarchical regression was used to determine the variables that significantly affected diversity values. Hierarchical regression (multi-level modeling) is organised at multiple levels, a three level model was used in this study. In the analyses, level three referred to the biogeoclimatic zone, level two was related to block, and level one included fixed classifications (nutrients, bulk density, slope etc.). A primary strength of this type of analysis is that the three level structure considers within and cross-level interactions (Osborne 1999; Chi and Voss 2005; Tabachnick and Fidell 2007) such as those considered in this study. The hierarchical regression model was:

$$\gamma_{ijk} = \mu + \mu_{i..} + \mu_{ij.} + \epsilon_{ijk}$$

where γ_{ijk} was the dependent variable, μ was the grand mean, $\mu_{i..}$ was the mean of level 2, $\mu_{ij.}$ was the mean of level 3, and ϵ_{ijk} was the error term. From this model, the standard deviation that accounted for zone, block, and residual standard deviation were included in the tables.

Statistical analysis was performed using STATA® 13.1 (StataCorp LP, College Station, Texas, USA). Species diversity was the dependent variable considered for analysis, and independent variables included soil properties, topography (blocks were assigned according so aspect), treatment, and zone. A 95% confidence level was used for the models. Regression reporting included the coefficient, standard error, random effects, and *p* value, and results were considered significant when $\alpha \leq 0.05$.

5.4 Results

The species diversity values met the assumption of normality using the Shapiro Wilk test ($\alpha = < 0.05$, $p = 0.212$); an ANOVA for species diversity considered differences in mean H' values between treatment, block, and zone. Significant differences were shown in species diversity between treatment ($F_{2,149} = 8.33$, $p = 0.000$) and block ($F_{3,20} = 8.67$, $p = 0.000$) but not between zones ($F_{1,75} = 1.85$, $p = 0.178$). A Tukey test was conducted to find where the differences were located, and for treatments, the significant differences were observed between control and pine ($p = 0.001$), but not between cinquefoil and control ($p = 0.249$) or between pine and cinquefoil ($p = 0.221$) (Figure 17). By block, the Tukey test returned significant differences between wetland and south facing blocks ($p = 0.020$), and wetland and crest position blocks ($p = 0.001$) (Figure 18).

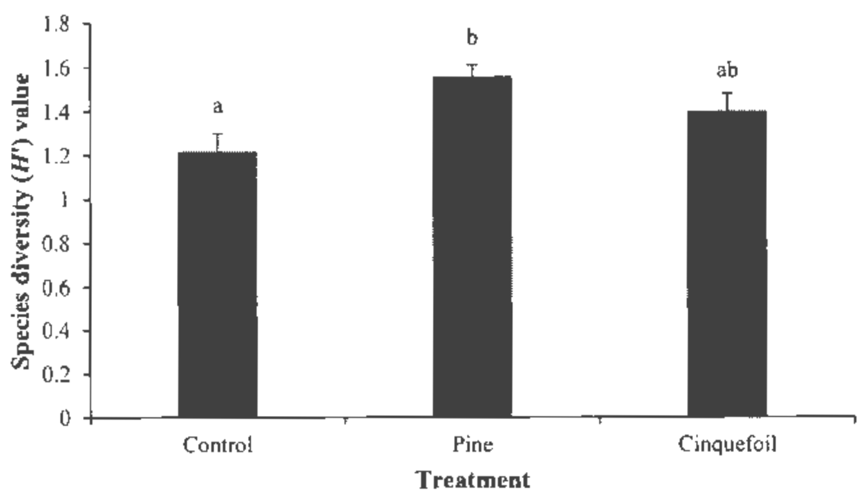


Figure 17. Mean with standard error of species diversity (H') value by treatment. Control n = 72, pine n = 55, cinquefoil n = 23. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

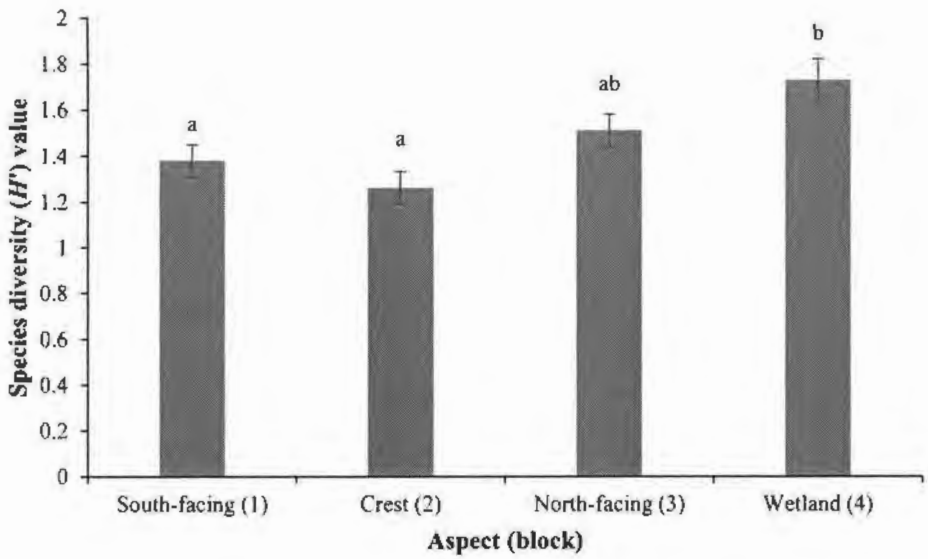


Figure 18. Mean with standard error of species diversity (*H'*) value by aspect (block). Control n = 72, pine n = 55, cinquefoil n = 23. Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

Observed plant types were variable between control plots and treatment plots. Tree observations were highest in pine plots, and lowest in cinquefoil plots (see Appendix 3 for numbers by plant type). Shrub observation numbers were highest in cinquefoil plots. Pine plots had higher numbers of herbs, followed by cinquefoil plots and control plots. For graminoid (grass) species, observations were highest in cinquefoil plots in the BWBS 2, 3, and 4, and ESSF 3 blocks.

Species diversity varied between treatments, but was more consistent in pine plots than for cinquefoil plots (Figure 19, Table 12, Table 13). Natural regeneration values between treatments were variable in the BWBS zone; in the BWBS 1 and 3 blocks, diversity was highest in pine plots, while in BWBS 2 and 4 blocks, diversity was highest in cinquefoil plots. In the ESSF zone, species diversity was highest in pine plots in ESSF 1, 2, and 4 blocks, and highest in cinquefoil plots in the ESSF 3 block. Species diversity throughout the study site was consistently lowest in control plots in each block.

In upland BWBS and ESSF blocks, fireweed (*Chamerion* (*Epilobium*) *angustifolium*) was recorded in 106 of 120 plots. Occurrences in plots upland ESSF blocks was less (n = 50) than for BWBS (n = 56) blocks. At lowland blocks, this species occurred in two plots in the BWBS 4 block, and one plot in the ESSF 4 block. There were very few observations of naturally regenerated lodgepole pine seedlings in any of the upland blocks, and no observations of lodgepole pine in either of the wetland blocks. There were no observations of natural regeneration of shrubby cinquefoil in any block.

5.4.1 Species Diversity

Table 12. Mean and standard error (in parentheses) of naturally regenerated species diversity, abundance, and Shannon Diversity Index (H') value of upland blocks. For each upland block, n = 9 for control plots, n = 8 for pine plots, and n = 3 for cinquefoil plots.

Block	Treatment	Species Richness	Species Abundance	H' value (Diversity)
BWBS 1	Control	6.67 (1.66)	53.22 (15.06)	1.25 (0.33)
	Pine	9.38 (2.26)	103.50 (23.14)	1.48 (0.22)
	Cinquefoil	7.67 (2.08)	82.00 (35.03)	1.41 (0.17)
BWBS 2	Control	5.33 (1.32)	34.22 (13.98)	1.28 (0.25)
	Pine	6.75 (0.71)	74.86 (32.59)	1.35 (0.18)
	Cinquefoil	7.00 (1.00)	55.67 (12.34)	1.45 (0.06)
BWBS 3	Control	6.89 (3.14)	45.44 (18.66)	1.38 (0.41)
	Pine	11.75 (3.85)	102.75 (31.77)	1.86 (0.43)
	Cinquefoil	7.33 (1.53)	87.00 (40.58)	1.48 (0.22)
ESSF 1	Control	4.22 (1.79)	24.78 (19.66)	1.06 (0.35)
	Pine	7.63 (2.13)	74.63 (26.61)	1.56 (0.29)
	Cinquefoil	4.67 (2.08)	27.00 (19.52)	1.08 (0.45)
ESSF 2	Control	2.44 (1.81)	10.44 (14.83	0.67 (0.56)
	Pine	7.13 (1.64)	72.25 (40.87)	1.52 (0.35)
	Cinquefoil	2.33 (2.52)	5.67 (5.51)	0.70 (0.74)
ESSF 3	Control	4.44 (1.81)	41.11 (19.63)	1.11 (0.32)
	Pine	7.38 (2.50)	81.13 (32.47)	1.36 (0.40)
	Cinquefoil	8.67 (4.73)	111.33 (15.70)	1.53 (0.27)

Table 13. Mean and standard error (in parentheses) of naturally regenerated species diversity, abundance and Shannon Diversity Index (H') values of wetland blocks. In BWBS 4, control n = 9 pine n = 3*, cinquefoil n = 2**; in ESSF 4, control n = 9, pine n = 4, cinquefoil n = 3.

Block	Treatment	Species Richness	Species Abundance	H' value (Diversity)
BWBS 4	Control	7.11 (1.27)	63.89 (14.80)	1.42 (0.18)
	Pine	6.67 (1.53)	68.67 (17.62)	1.42 (0.03)
	Cinquefoil	9.00 (1.41)	127.00 (9.90)	1.72 (0.11)
ESSF 4	Control	9.44 (3.88)	74.11 (32.18)	1.55 (0.60)
	Pine	14.25 (2.63)	137.75 (52.50)	2.17 (0.21)
	Cinquefoil	11.67 (2.08)	81.00 (26.51)	1.94 (0.30)

* One pine plot disregarded due to ongoing plot disturbance by human activities.

** Two plots planted with cinquefoil in BWBS 4.

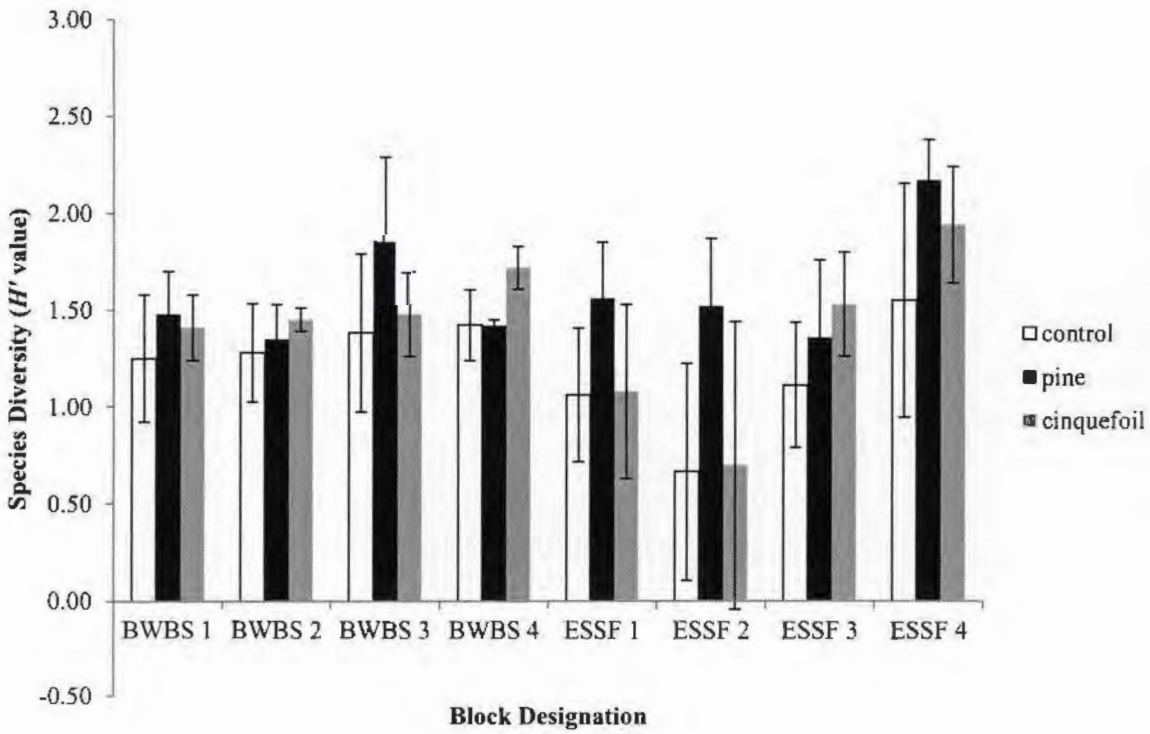


Figure 19. Mean and standard error (error bars) of natural regeneration Shannon Diversity Index (H') values for control, pine and cinquefoil plots, all blocks. Plot numbers for each upland block: control n = 9, pine n = 8, cinquefoil n = 3. For wetland blocks, BWBS 4, control n = 9, pine n = 3*, cinquefoil n = 2**; ESSF 4, control n = 9, pine n = 4, cinquefoil n = 3.

* One pine plot disregarded due to ongoing disturbance by human activities

** Two plots planted to cinquefoil in BWBS 4.

ANOVAs were run for species diversity to determine whether there were significant differences in control, pine, and cinquefoil plots, based on the *H'* values calculated from natural regeneration. The factor variables were significant ($p < 0.05$) for the controls by treatment ($F_{2,72} = 10.87$, $p = 0.000$), and by block ($F_{3,9} = 8.83$, $p = 0.000$) but not by zone ($F_{1,72} = 1.85$, $p = 0.178$).

Table 14. Hierarchical regression for species diversity in combined control, pine and cinquefoil plots, all blocks.

Variable	β	β SE	p (< 0.05)
Moisture	0.01	0.01	0.200
N	1.35	0.59	**0.023***
C	-0.04	0.02	**0.017***
S	0.12	0.64	0.852
P	0.01	0.00	**0.008***
K	-0.41	0.61	0.495
CEC	0.00	0.01	0.981
pH	-0.06	0.05	0.276
Bulk Density	0.35	0.13	**0.007***
Elevation	0.00	0.00	0.139
Soil temp.	0.00	0.17	0.995
LFH	-0.07	0.37	0.846
Slope	0.01	0.00	**0.000***
Clay	0.01	0.01	0.575
Treatment	0.11	0.03	**0.001***
Random effects:			
Zone (SD)	9.45E-13		
Block (SD)	9.11E-13		
SD (residual)	0.2264471		

* Significant at < 0.05

The hierarchical regression (Wald chi^2 149.97, Prob > chi^2 = 0.000) (Table 14) for all treatments, found that species diversity in all blocks was significantly affected by total N, total C, available P, soil bulk density, slope, and treatment. As the clay percentage was not considered significant in the model, a separate regression was performed for each treatment, and excluded clay as a variable (Table 15).

Table 15. Hierarchical regression for species diversity in separate control, pine and cinquefoil plots, all blocks.

	Control			Pine			Cinquefoil		
Variable	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)
Moisture	0.00	0.00	0.087	0.00	0.00	0.405	0.01	0	**0.000***
N	0.02	0.03	0.374	-0.21	0.03	**0.000***	-1.69	0.23	**0.000***
C	0.00	0.00	0.186	0.01	0.00	**0.000***	0.06	0.01	**0.000***
S	-0.02	0.04	0.710	-0.41	0.05	**0.000***	2.19	0.29	**0.000***
P	0.00	0.00	0.216	0.00	0.00	0.739	0.00	0.00	0.769
K	0.00	0.04	0.922	-0.04	0.06	0.503	0.24	0.14	0.080
CEC	0.00	0.00	0.994	0.00	0.00	**0.000***	0.00	0.00	0.881
pH	0.02	0.01	**0.025***	-0.04	0.01	**0.000***	0.10	0.03	**0.001***
Bulk Density	0.18	0.02	**0.000***	-0.31	0.02	**0.000***	0.40	0.04	**0.000***
Elevation	0.00	0.00	**0.000***	0.00	0.00	**0.000***	0.00	0.00	**0.000***
Soil temp.	0.16	0.01	**0.000***	0.40	0.02	**0.000***	0.00	0.04	0.952
LFH	0.56	0.19	**0.004***	0.40	0.34	0.256	0.04	0.19	0.834
Slope	0.02	0.00	**0.000***	0.00	0.00	0.387	0.20	0.00	**0.000***
Random effects:									
Zone (SD)	2.24E-13			9.88E-12			3.40E-13		
Block (SD)	1.90E-01			3.34E-01			1.59E-01		
SD (residual)	0.0205574			0.580154			0.0445749		

* Significant at < 0.05

5.5 Discussion

Species diversity observations showed that plant species diversity varied by slope aspect of each block. Wetland blocks had high species diversity, while south-facing and crest blocks were the least diverse by plant species noted. Treatment was also related to species diversity in many of the research blocks; control plots were generally the least diverse, and pine plots often had the highest diversity values within each block.

5.5.1 Aspect

The arrangement of blocks by aspect allowed for distinctions to be made about species diversity relative to aspect in this study. South-facing and crest blocks had comparably low diversity, and were statistically similar to each other. Higher values of diversity were observed in north-facing blocks and wetland blocks in both biogeoclimatic zones.

5.5.1.1 South-facing Blocks

The south-facing blocks had low species diversity (Figure 20). Diversity was lowest in control plots and highest in pine plots in both biogeoclimatic zones. Both BWBS and ESSF blocks were adjacent to mature pine stands, however the BWBS 1 block was adjacent to a frequently used access road for pipeline maintenance, while the ESSF 1 block was at a high elevation, and subjected to wind exposure due to the linear alignment of the right-of-way clearing. Some research has found that wind exposure in mountainous environments can adversely affect plant establishment (Litaor *et al.* 2008), which was more noticeable at the ESSF 1 block in this study.

Figure 20. Images of south-facing blocks (top: BWBS 1, bottom: ESSF 1) showing natural regeneration recovery.

5.5.1.2 Crest Position Blocks

The BWBS and ESSF 2 blocks both exhibited low levels of plant species diversity (Figure 21). This finding is consistent with other research, which has asserted the crest positions have shallow topsoil and low moisture values, which can be limiting factors to plant establishment (Zinko *et al*. 2005; Pareliussen *et al*. 2006). Soil moisture however, was not a significant contributor to species diversity in this study although values were lowest at crest blocks in both biogeoclimatic zones (see Chapter 4). In the BWBS 2 block, highest mean diversity was observed in the cinquefoil plots, while pine plots had the highest diversity values in the ESSF 2 block. Both blocks were adjacent to a mature lodgepole pine stand, although the BWBS 2 block was part of a wider right-of-way, as a winter road was present on the west side of the block. The ESSF 2 block was at high elevation on a conspicuous hill which was also exposed to prevalent winds.

Figure 21. Images of crest position blocks (top: BWBS 2, bottom: ESSF 2) showing natural regeneration recovery.

5.5.1.3 North-facing Blocks

Each north facing block in this study was unique. The BWBS 3 block was adjacent to a mature mixedwood stand, and nutrient, temperature and moisture levels were influenced by leaf litter and the density and alignment of CWD application. The ESSF 3 block was adjacent to a pure conifer stand, and arrangement of CWD was lower in volume, and aligned more randomly than in the BWBS 3 block (Figure 3, Figure 22, Figure 23). Species diversity was high for all treatments in the BWBS 3 block compared to BWBS 1 and 2 blocks. Species diversity was low in the pine plots relative to ESSF 1 and 2 blocks in the ESSF zone, but higher in control and cinquefoil plots compared to other ESSF upland blocks.

Figure 22. Image of north-facing BWBS block showing natural regeneration recovery.

Site soil richness is an indicator of diversity potential (Widenfalk and Weslien 2009), and the BWBS 3 block soil property observations showed greater nitrogen, carbon, sulphur and potassium values than the other upland blocks in the BWBS zone (refer to soil properties results in Chapter 4). The mean species diversity in this block was highest for all treatments, however there was also greater variability of diversity observed. The higher species diversity for uplands observed in this study is supported by other research (De Bello *et al.* 2006).

Figure 23. Image of north-facing ESSF block showing natural regeneration recovery.

5.5.1.4 Wetlands

The wetland blocks in this study showed high species diversity values (Figure 24). The BWBS 4 block was adjacent to a black spruce stand, and had extensive colonization by the graminoid species bluejoint (*Calamagrostis canadensis*). This species was recorded in all control, cinquefoil and two of three pine plots. The height of the grass also provided a competitive advantage against planted pine and cinquefoil seedlings by the end of the 2013 growing season. This grass species has been noted as a common invader of disturbed sites in northeastern B.C. (Macey and Winder 2001; Krzic *et al.* 2003), generally as a result of increased light availability (Maundrell and Hawkins 2004).

Figure 24. Images of wetland blocks (top: BWBS 4, bottom: ESSF 4) showing natural regeneration recovery.

Species diversity and abundance varied by treatment in ESSF 4. This block had a relatively high diversity of wetland species. The block was at the intersection of two resource roads, and other research has found negative correlations between human activities and species richness (Houlahan *et al.* 2006). Bluejoint appeared in many of the plots within this block, but there were also willow (*Salix spp.*) species, various wetland sedges (*Carex spp.*), and tamarack (*Larix* *laricina*) was regenerating naturally (there were plots planted with tamarack in this block), and there were mature individuals off the pipeline right-of-way.

Nitrogen levels between treatments and controls were not significantly different, although the regression models highlighted that total nitrogen was negatively correlated with species diversity in the planted plots, but positively correlated for the controls. Net N accumulation has been asserted as a driver for increased species composition over time (Bobbink *et al.* 2010), and this study noted greater H' values in blocks (BWBS 4, ESSF 4) where total N was high.

5.5.2 Treatment

Species diversity varied by treatment in the study blocks. There was a significant difference observed between control and pine plots, but not between pine and cinquefoil or control and cinquefoil. Low species diversity was observed in control plots, while natural regeneration was variable between pine and cinquefoil plots.

5.5.2.1 Control Plots

The control plots consistently had lower species diversity than pine or cinquefoil plots, likely due to smaller plot area (Brummer *et al.* 1994; Zdenka and Milan 2006), which was a flaw in the experimental design. There were plots in the ESSF 2 block where no natural regeneration was observed, and in the BWBS 4 block, the species diversity value in control plots was the same as in the pine plots. The control plots however, had lower diversity in all study blocks than either the pine or cinquefoil treatment, and the results of this study are consistent with other work that examined the influence of soil disturbance correlated with lower species diversity (Peltzer *et al.* 2000).

Soil properties including pH, bulk density and soil temperature, presence of OM, elevation, and slope influenced species diversity in control plots. Elevation was negatively correlated with species diversity, and diversity values were lowest at the ESSF 2 block (elevation 1369 m.a.s.l). Soil pH was low in ESSF upland blocks, which could account for the association between higher pH and higher diversity values. Slope was positively associated with diversity, but this may have been a confounding effect, as crest blocks and wetland blocks were on level ground, and the associated diversity was low at crest blocks, and high in wetland blocks.

5.5.2.2 Pine Plots

Pine plots had the highest species diversity in five of the eight research blocks. This was observed in both the BWBS and ESSF 1 blocks, and less consistently for the other slope positions. The diversity values were higher in three ESSF blocks and two BWBS blocks. Lowland species diversity in the ESSF 4 block was greatest in the lodgepole pine plots, which showed the greatest diversity by number of species, species abundance, and associated H' value. Depending on site conditions, lodgepole pine is not always a strong competitor and the young stand age did not demonstrate that it was outcompeting other species for resources such as light. The negative association between total N and species diversity in pine plots could be related to the low diversity value in the BWBS 4 block, where nitrogen levels were high. This block had extensive bluejoint abundance (Figure 25), and the prevalence of this species adversely influenced species richness in this block. Pine plots in upland blocks were given a fertilizer amendment (N:P:K 25:0:0) at planting. The N levels in pine plots were not higher than N values in control and cinquefoil plots when soil samples were taken in 2012, but the initial input of N fertilizer could have influenced establishment of naturally regenerated species soon after the

2010 planting year. This idea has been documented by research that evaluated the influence of N based fertilizer and plant species richness (Gough *et al.* 2000).

Figure 25. BWBS wetland block showing prevalence of bluejoint (*C. canadensis*).

5.5.2.3 Cinquefoil Plots

Species diversity was highest in cinquefoil plots in three of the eight research blocks. There was very little diversity however, in the ESSF 2 block in cinquefoil plots (Figure 26). The calculations of greater mean diversity were made for the BWBS 2 and BWBS 4 blocks, and the ESSF 3 block. There is some evidence that cinquefoil can act as a species richness facilitator in some alpine communities (Xu *et al.* 2010), although it was not consistent for slope position in this study. It is possible that the density of planted cinquefoil seedlings adversely affected species diversity and associated *H'* value, as this species can form a dominant cover in suitable conditions (Elkington and Woodell 1963).

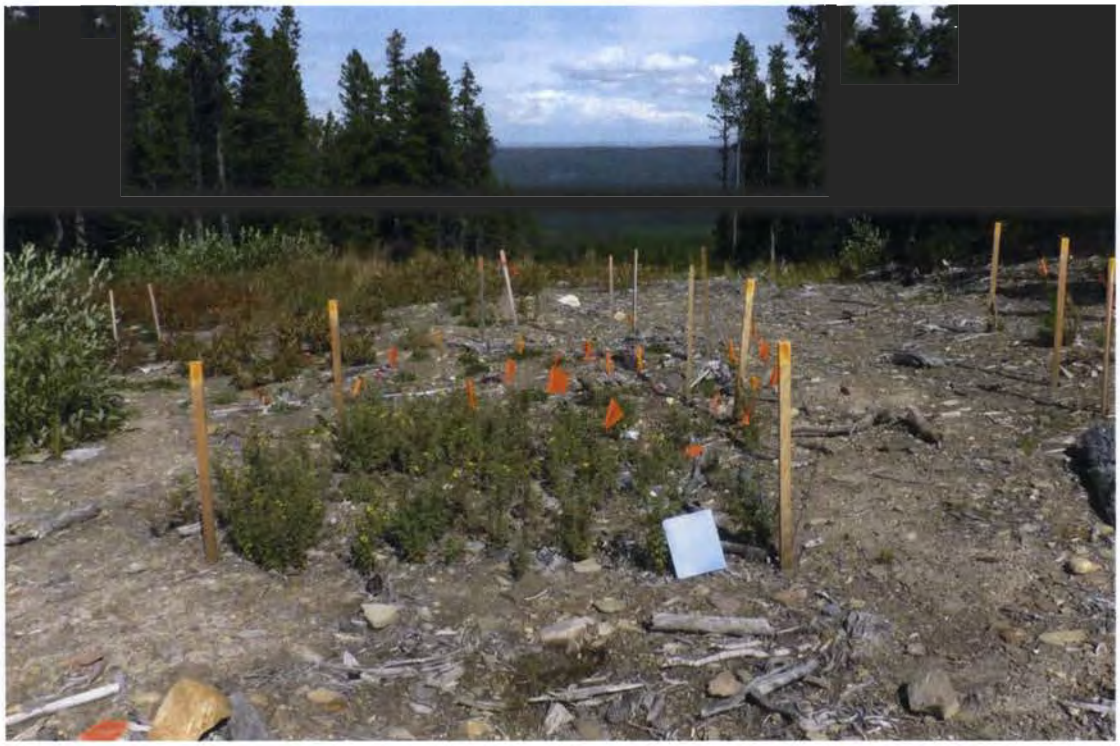


Figure 26. Cinquefoil plot at ESSF crest block, demonstrating low species diversity observations.

Results of the regression analysis showed that nitrogen, carbon, phosphorus, bulk density, slope and treatment were significant contributors to naturally regenerated plant species within the treatments. In upland blocks, pine seedlings were given a fertilizer addition at planting which may have temporarily increased total nitrogen levels, but the differences in nitrogen between treatments was not consistently higher in pine plots in 2012 when soil analyses were performed (see Chapter 4). Soil carbon values were highest in the BWBS 3 block, and the two wetland blocks (BWBS 4 and ESSF 4), but carbon values were not consistently associated with any of the treatments considered in this study. Available phosphorus was variable between the treatments, but was higher in the ESSF upland blocks than BWBS upland blocks and either of the wetland blocks. Planting density of shrubby cinquefoil was high, but planting density was not consistent with low species diversity in cinquefoil plots. Bulk density was a significant contributor to species diversity, however lowest bulk density values were observed in wetland blocks, where species diversity was higher than in upland blocks. ESSF 4 had the least amount of area affected by industrial activity for pipeline installation, and had the highest diversity values by zone and treatment. Slope was correlated with species diversity, but this may have been a confounding variable, as both crest and wetland blocks did not have a slope percentage, and wetland blocks had high diversity values, while crest position blocks had low diversity values by zone. The findings of this study are supported by other research that asserts wetlands are highly productive and dynamic ecosystems (Xiong *et al.* 2003; Økland *et al.* 2008).

The comparable species diversity in control plots with the treatments in the BWBS 4 block and the ESSF 2 block in this study suggest that there may be instances were natural regeneration is a plausible strategy, but the lower values should be cautionary as to the efficacy of natural regeneration as a reclamation option.

5.4.3 Limitations

This study did not consider ongoing disturbance as a variable, which may have impacted species diversity by suppressing species that are susceptible to mechanical damage, and for the potential for introduction of invasive species on vehicles. Soil samples were not analysed for seed bank content, which could have shown the diversity of viable seeds for future natural regeneration. Wind was not included in the analysis; it acts as a vector for seed dispersal in some plant species (Tackenberg *et al.* 2003), and inhibits successful seed establishment when high winds are combined with poor microsite preparation. The smaller size of control plots may have also contributed to consistently lower values of diversity compared to pine or cinquefoil plots. This could have been corrected by use of consistent plot sizes for control and treatment plots.

5.5 Conclusion

This study was conducted to determine the effects of industrial activities on the capacity of upland and wetland sites in mountainous areas of northeastern B.C. to recover naturally after human-based disturbances. The differences in species diversity between the control, pine, and cinquefoil treatments showed that planting increased species diversity in the BWBS and ESSF biogeoclimatic zones in this study. The lower species diversity in control plots than either of the treatments implies that planting programs can aid in natural regeneration of available seeds, but high density planting can inhibit species diversity, as was observed in cinquefoil plots. In this study, higher species diversity was observed in wetland blocks than in upland blocks. The number of species that were not identified also increased with greater species diversity, and accurate identification may have altered the numbers by plant type, but not overall diversity. The greater diversity observed in the ESSF wetland may be related to the greater length of time between the disturbance and the observation years in this study, although it is unclear if time would increase the species diversity in the upland blocks or the BWBS wetland block.

Future reclamation projects in the peace region of northeastern B.C. that encompass the BWBS and ESSF biogeoclimatic zones should include prescriptive planting, as the results of this study showed that unplanted areas had less natural regeneration than plots planted with lodgepole pine or shrubby cinquefoil at higher elevation sites in upland research blocks. The slope aspect variable and surrounding forest types provided valuable knowledge regarding the challenges to reclamation related to creating a functioning ecosystem along reclaimed pipeline right-of-ways. Other considerations should be given to traditional use of the land, and input from local First Nations would provide insight to augmenting planting projects with cultural keystone native plant species for food or medicinal values.

6.0 Growth and Survival of Lodgepole Pine and Shrubby Cinquefoil on a Reclaimed Natural Gas Pipeline Right-of-Way in Northeastern British Columbia

Abstract

Environmental conditions in boreal forests of western Canada can be challenging to plant growth. Construction of a disturbance such as a pipeline right-of-way creates aboveground and substrate disturbance factors that can affect environmental quality. The study objective was to determine the growth and survival of lodgepole pine (*Pinus contorta* var. *latifolia*) and shrubby cinquefoil (*Dasiphora fruticosa*) on a reclaimed natural gas pipeline in northeastern British Columbia. Lodgepole pine seedlings were measured for aboveground height, stem diameter, and height diameter ratio (HDR). Shrubby cinquefoil seedlings were measured for total height, stem count and cover area. There was greater average plant height at BWBS upland and wetland blocks than at ESSF upland and wetland blocks for lodgepole pine and shrubby cinquefoil seedlings. The findings suggest that soil physical and chemical properties can influence plant growth, and reclamation practitioners should consider site conditions when determining species use in reclamation projects.

6.1 Introduction

Forest fragmentation from natural gas infrastructure in northeastern B.C. is replacing natural disturbance patterns of boreal forests. Natural disturbance patterns such as fire, wind and insect outbreaks open forest canopies and facilitate establishment of plant species that produce serotinous cones. Industrial disturbances in boreal forest ecosystems do not emulate natural disturbances, and there is a need to understand the differences between natural and industrial disturbances, and the role of industrial disturbance to plant growth in high elevation boreal forests.

Industrial disturbances in the south Peace region of northeastern B.C. have increased in recent years, and have exacerbated forest fragmentation from existing natural disturbance regimes and forest harvesting. Pipeline construction creates linear forest canopy gaps, removes vegetation, compromises forest soil horizons, and affects soil temperature and soil moisture regimes (Naeth *et al.* 1987; Shi *et al.* 2014). Displacement or loss of soil horizons, removal of canopy cover, edge effect, changes in levels of exposure to minerals and macronutrients, erosion potential, and alterations in soil moisture and temperature regimes, all alter growing conditions for plants (Mariani *et al.* 2006; Hope 2007).

Although the impacts to vegetation from forestry and vegetation management are well documented, plant growth after pipeline installations in northeastern B.C. is less well understood. In order to comprehend plant growth after linear forest harvest and soil horizon disturbance, it is important to determine how plants respond to altered forest soils.

The primary objective of this study was to determine the effects of industrial disturbance on plant growth and survival of two selected plant species, lodgepole pine (*Pinus contorta* var.

latifolia), and shrubby cinquefoil (*Dasiphora fruticosa*) along a reclaimed natural gas pipeline right-of-way in the Boreal White and Black Spruce zone (wet cool subzone) and the Engelmann Spruce – Subalpine Fir zone (moist very cold subzone) in northeastern B.C.

6.2 Materials and Methods

6.2.1 Study Site and Experimental Design

The Ojay research site was situated in a mature managed lodgepole pine stand. Lodgepole pine dominated the tree canopy in most upland blocks, although one block was adjacent to a mixedwood stand. Identified canopy species off pipeline at upland blocks included lodgepole pine (*Pinus contorta*) at all upland blocks, and at one block in the BWBS zone, trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*) were also observed. Off pipeline tree species noted at wetland blocks included black spruce (*Picea mariana*), and tamarack (*Larix laricina*).

The Ojay pipeline was constructed in 2008 in northeastern B.C. In 2010, eight blocks were selected by representatives of Shell Canada for experimental planting at upland and wetland sections of the pipeline right-of-way (see Chapter 3 for further site details). Within each block, there were plots planted with lodgepole pine (eight in each upland block, four in each wetland block), and shrubby cinquefoil (three in each block except BWBS 4, where two cinquefoil plots were established and planted.

6.2.2 Sampling and Data Collection

In June 2012, pine and cinquefoil seedlings were identified and tagged within each plot. Exclusion and inclusion criteria involved confirmation of plot boundaries with a 2 m x 2 m square, and seedlings with fifty percent or more of the main stem outside the square were excluded from future measurement.

Table 16. Biogeoclimatic zone, block designation, and numbers of pine and cinquefoil seedlings selected for monitoring in 2012 and 2013.

Block	Designation*	Pine Seedlings measured		Cinquefoil Seedlings measured	
		2012	2013	2012	2013
BWBS	1	96	96	15	15
BWBS	2	94	94	15	15
BWBS	3	80	80	14	14
BWBS	4	36†	36†	9‡	9‡
ESSF	1	67	67	15	15
ESSF	2	72	67	14	14
ESSF	3	68	66	13	13
ESSF	4	43	43	15	15
	n =	556	549	110	110

BWBS- Black White Boreal Spruce biogeoclimatic zone
ESSF- Engelmann Spruce Subalpine Fir biogeoclimatic zone
*Block description
1 – South-facing block
2 – Crest block
3 – North-facing block with CWD amendment
4 – Wetland block
†- One pine plot disregarded due to ongoing disturbance
‡- Two cinquefoil plots were established

Lodgepole pine and shrubby cinquefoil seedlings were monitored for survival and growth in August 2012 and 2013. All living pine seedlings in all blocks were measured, and one quarter of planted cinquefoil seedlings per plot were selected for measurement (Table 16). Measurement of pine seedlings was based on guidelines from the BC Ministry of Forests Land and Natural Resource Operations (BC MFLNRO) for plants measuring less than 3 metres. In samples where the main stem was dead, but there was evidence of compensatory growth from a lateral stem, height measurement for the tallest lateral leader was taken. Stem diameter was taken from a point of the stem 1 cm from soil surface, where two diameter measurements were taken. Stem diameter was measured with calipers, and plant height measured with a carpenter's measuring tape. Height-Diameter Ratio (HDR) was calculated for lodgepole pine by dividing the tree height (cm) by the stem diameter (cm) (Opio *et al.* 2003). For cinquefoil seedlings, total height, cover area by two cross-sectional measurements were recorded, and stems for each sample plant were counted. Any damage to plants caused by biotic or abiotic factors was noted, and any plants that died or otherwise missing throughout the data collection period were excluded from final analysis except as a measure of plant survival.

In the second year of data collection, some samples were harvested for biomass measurements. Guidelines for sampling of tree seedlings and understory herbs followed those used by the Canadian Forest Service (Catchpole and Wheeler 1992; Tremblay and Larocque 2001; Miao and Li 2007). Samples were weighed as wet samples, and then oven dried at 70° C for five days, after which samples were re-weighed, and dry weights were recorded for each sample. Each sample plant was then cut and weighed separately for aboveground (stems and leaves) and belowground (roots) measurements.

6.2.3 Data Analysis

Soil physical and chemical properties including temperature, moisture, bulk density, pH, carbon, nitrogen, sulphur, phosphorous, potassium, cation exchange capacity, particle size, plus slope and elevation were considered as independent variables in this study (see chapter 4 and Appendix 1 for comprehensive methods and analysis). Species diversity (species richness and species abundance; see Chapter 5 for results) was also considered to determine potential effects of competition to survival and growth of lodgepole pine and shrubby cinquefoil.

Plant growth data were subjected to the Shapiro-Wilk test for normality, as it is considered statistically more powerful in comparison to some other methods (Kolmogorov-Smirnov, Lilliefors, and Anderson-Darling tests (Razali and Yap 2011)). An ANOVA was performed to determine if growth parameters were significantly different between zones and blocks. Where significant differences were recorded in the ANOVAs, a Tukey test was performed to discern the likely areas of significant differences. Where the Tukey test returned significant differences, a letter was assigned to the group. The first mean was given the letter "a", and where differences were observed in the analysis, a letter "b" was applied. Variables with the same letter ("a", or "ab") were not considered statistically significant at $\alpha = 0.05$.

A step-wise regression was initially proposed to analyse the data, however, many collinearity problems emerged in the analysis results, so a hierarchical regression was used to determine the variables that significantly affected diversity values. Hierarchical regression (multi-level modeling) is organised at multiple levels; a three level model was used in this study. In the analyses, level three referred to the biogeoclimatic zone, level two was related to block, and level one included fixed classifications (nutrients, bulk density, slope etc.). A primary strength of this type of analysis is that the three level structure considers within and cross-level interactions (Osborne 1999; Chi and Voss 2005; Tahachnick and Fidell 2007) such as those considered in this study. The hierarchical regression model was:

$$\gamma_{ijk} = \mu + \mu_{i..} + \mu_{ij.} + \epsilon_{ijk}$$

where γ_{ijk} was the dependent variable, μ was the grand mean, $\mu_{i..}$ was the mean of level 2, $\mu_{ij.}$ was the mean of level 3, and ϵ_{ijk} was the error term. This regression analysis allowed us to determine which independent variables were most important in determining the best location for a give plant species.

Statistical analysis was performed using STATA® 13.1 (StataCorp LP, College Station, Texas, USA). Dependent variables considered for analysis included growth parameter measurements and plant survival, and independent variables included soil physical and chemical properties, topography, block, and biogeoclimatic zone. A 95% confidence level was used for the models. Regression reporting included the coefficient, standard deviation, random effects parameters, and p value; results were considered significant when $\alpha < 0.05$.

6.3 Results

Lodgepole pine seedling growth was complex, as plants were taller in north-facing block, while total biomass was highest in crest block in both the ESSF and BWBS biogeoclimatic zones. Pine mortality was consistently higher in the ESSF zone than the BWBS zone. Shrubby cinquefoil seedlings were also tallest in BWBS and ESSF 3 blocks, yet total biomass was greatest in BWBS and ESSF 1 blocks. Growth and biomass of lodgepole pine and shrubby cinquefoil was low in wetland blocks.

6.3.1 Plant Growth

Lodgepole pine seedlings were measured for total height, stem diameter, HDR; and shrubby cinquefoil seedlings were measured for total height, and cover area. In August 2013, representative individuals from each planted plot were destructively sampled, and both species were weighed for aboveground, belowground, and total biomass.

6.3.1.1 Lodgepole Pine

Plant growth and survival data were subjected to the Shapiro-Wilk test for normality. The height data for pine met the criteria for normality at $\alpha = 0.05$ ($p = 0.493$). Pine stem diameter was also normal at $\alpha = 0.05$ ($p = 0.086$). The ANOVA for plant height showed significant differences in pine height means by block ($F_{3, 95} = 3.58$, $p = 0.020$) and by zone ($F_{1, 330} = 9.76$, $p = 0.003$). The Tukey test for pine height observed significant differences between 1 and 3 blocks ($p = 0.024$) (Figure 27).

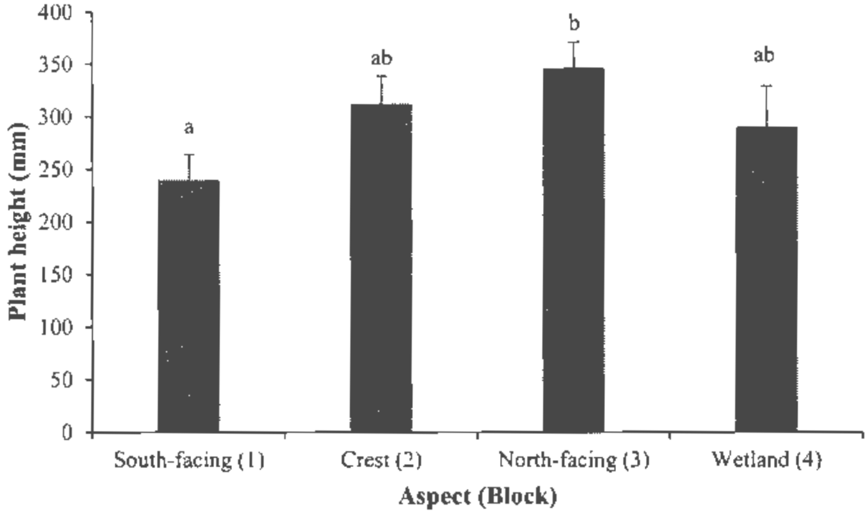


Figure 27. Mean and standard error of pine seedling height by block. Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

The ANOVA results for stem diameter of pine seedlings showed significant differences between means by block ($F_{3, 95} = 4.86$, $p = 0.005$), but not by zone ($F_{1, 330} = 0.16$, $p = 0.695$) (Figure 28). The results of the Tukey test observed significant differences between south-facing and crest blocks ($p = 0.009$), and between crest and wetland blocks ($p = 0.014$).

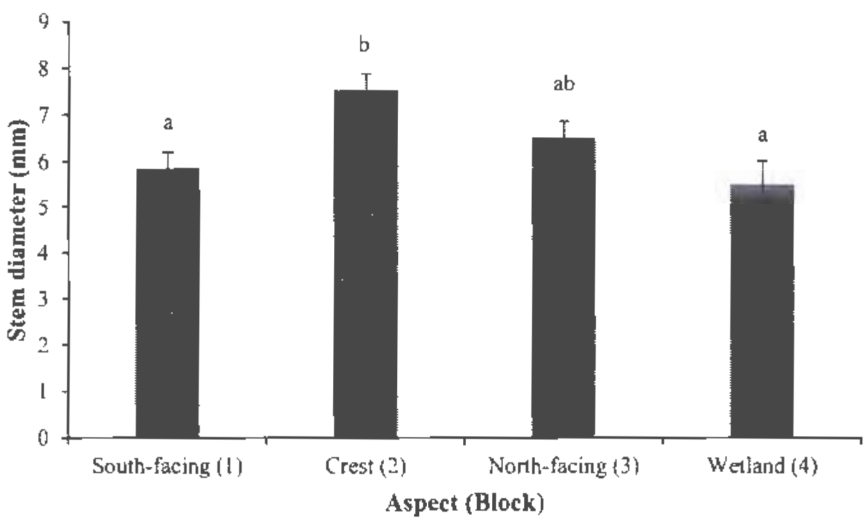


Figure 28. Mean stem diameter with standard error by aspect (block). Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

For lodgepole pine, average change in seedling height growth between 2012 and 2013 was greatest at ESSF and BWBS 2 blocks (Figure 29, Table 17, Table 18). Height accumulations were lowest in BWBS and ESSF 4 blocks (57.78 mm average for BWBS 4; 40.09 mm average for ESSF 4). ANOVA results for pine height between biogeoclimatic zones showed that differences in plant height between zones ($F_{1, 330} = 54.97, p = 0.000$) and blocks ($F_{3, 95} = 14.44, p = 0.000$) were significant. For stem diameter, the difference was not significant between zones ($F_{1, 330} = 0.67, p = 0.412$) but was significant between blocks ($F_{3, 95} = 27.61, p = 0.000$).

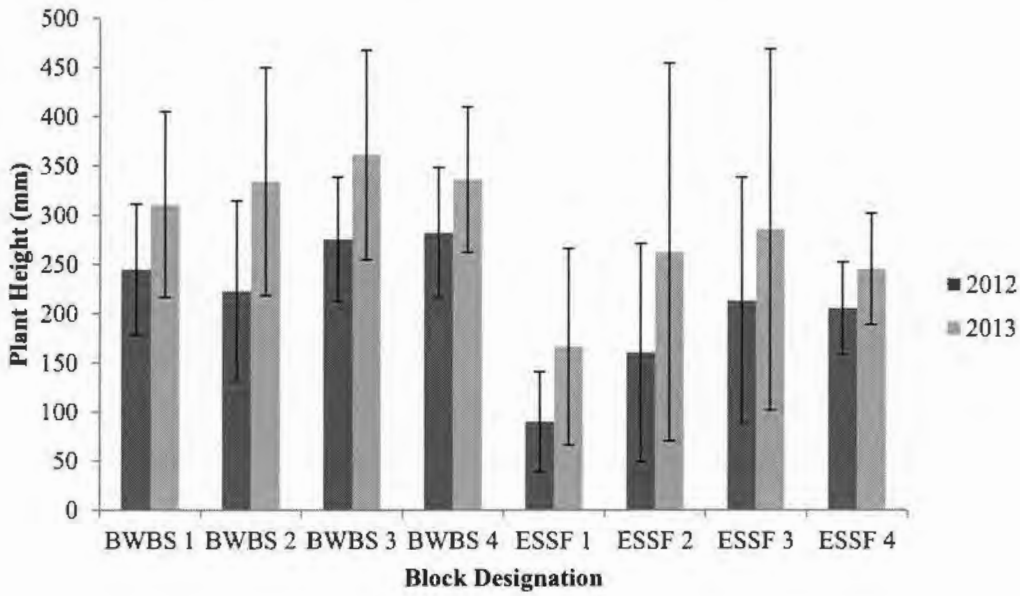


Figure 29. Mean plant height with standard error (lodgepole pine) for 2012 and 2013 seasons. BWBS 1 n = 96, BWBS 2 n = 94, BWBS 3 n = 80, BWBS 4 n = 37; ESSF 1 n = 62, ESSF 2 n = 66, ESSF 3 n = 68, ESSF 4 n = 43.
* Numbers effective in 2013, and immediately prior to destructive sampling.

The model for stem diameter (Wald $Chi^2 = 35.33$, Prob > $Chi^2 = 0.000$) showed that, of the variables considered, soil bulk density and slope were significant contributors to pine stem diameter. Bulk density was positively associated with stem diameter, and slope was negatively associated with stem diameter (Table 20).

Table 17. Mean plant height and stem diameter with standard error ((±) reported in parentheses) of upland lodgepole pine for 2012 and 2013, plus mean change between measurement years.

Block	2012 Height (mm)	2012 Stem diameter (mm)	2013 Height (mm)	2013 Stem Diameter (mm)	Interannual change Height (mm)	Interannual change Stem Diameter (mm)
BWBS 1	244.64 (66.44)	4.62 (0.93)	311.45 (94.17)	6.13 (1.42)	66.81 (46.03)	1.51 (0.82)
BWBS 2	223.05 (91.71)	5.04 (1.19)	333.91 (115.63)	7.46 (2.02)	110.86 (55.17)	2.41 (1.29)
BWBS 3	276.50 (63.70)	4.25 (.079)	370.20 (90.45)	6.34 (1.40)	93.70 (41.74)	2.09 (0.96)
ESSF 1	92.43 (52.35)	3.85 (1.73)	170.75 (97.01)	5.60 (2.25)	88.56 (54.64)	1.57 (1.54)
ESSF 2	159.66 (113.44)	5.22 (2.05)	261.99 (191.97)	7.82 (3.29)	124.03 (86.16)	2.26 (2.03)
ESSF 3	213.01 (130.44)	4.83 (1.94)	284.87 (183.58)	6.42 (2.35)	79.92 (62.78)	1.25 (2.31)

BWBS 1 n = 96, BWBS 2 n = 94, BWBS 3 n = 80; ESSF 1 n = 62, ESSF 2 n = 66, ESSF 3 n = 68.

Table 18. Mean plant height stem diameter and interannual change (standard error reported in parentheses) of lodgepole pine in wetland blocks.

Block	2012 Height (mm)	2012 Stem diameter (mm)	2013 Height (mm)	2013 Stem Diameter (mm)	Interannual change Height (mm)	Interannual change Stem Diameter (mm)
BWBS 4	282.27 (66.22)	4.61 (0.93)	336.22 (73.71)	5.84 (1.23)	57.78 (31.99)	1.23 (0.69)
ESSF 4	204.72 (46.93)	4.01 (0.58)	244.81 (56.39)	5.05 (0.96)	40.09 (30.80)	1.04 (0.74)

BWBS 4 n = 37, ESSF 4 n = 43.

Height diameter ratio data were not normally distributed ($p = 0.011$) in this study. The ANOVA showed significant differences by block ($F_{3, 95} = 8.09$, $p = 0.000$) and by zone ($F_{1, 330} = 30.14$, $p = 0.000$). The Tukey test found significant differences between 1 and 3 blocks ($p = 0.023$) and north-facing and crest blocks ($p = 0.020$) (Figure 30). The Tukey test returned a significant difference between zones ($p = 0.000$). The mixed effects regression performed for HDR (Wald chi^2 117.01, prob > chi^2 = 0.000) (Table 20) showed that soil moisture, elevation, and species richness were negatively correlated with HDR, and phosphorus, potassium, pH, and species abundance were positively correlated.

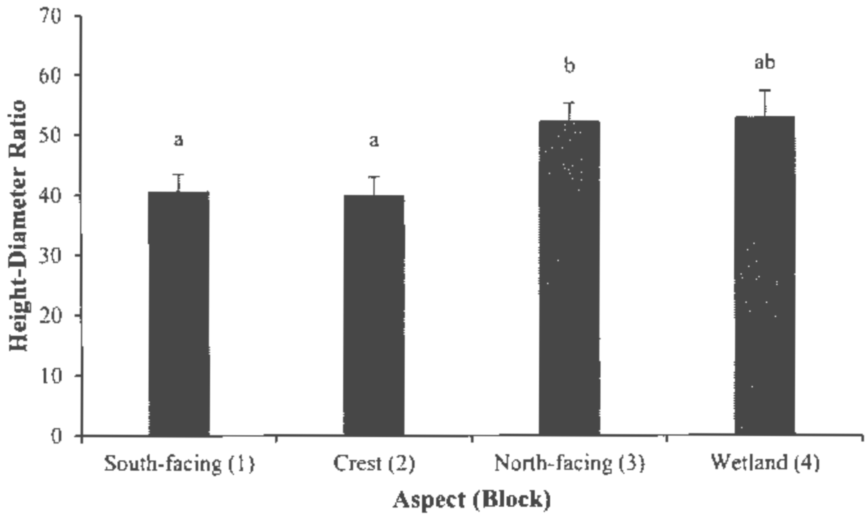


Figure 30. Mean and standard error of Height-Diameter Ratio by block. Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

Table 19. Height diameter ratio (HDR) for lodgepole pine in 2012 and 2013 plus interannual change; standard error (±) reported in parentheses. BWBS 1 n = 96, BWBS 2 n = 94, BWBS 3 n = 80, BWBS 4 n = 37; ESSF 1 n = 62, ESSF 2 n = 66, ESSF 3 n = 68, ESSF 4 n = 43.

	HDR 2012	HDR 2013	Interannual change
BWBS 1	53.09 (10.83)	50.79 (9.35)	-2.30
BWBS 2	44.13 (16.14)	44.98 (10.90)	0.86
BWBS 3	65.69 (12.92)	58.53 (9.40)	-7.16
BWBS 4	61.12 (13.89)	58.45 (11.10)	-2.67
ESSF 1	25.54 (11.55)	33.41 (10.99)	7.87
ESSF 2	30.45 (15.97)	35.92 (16.41)	5.48
ESSF 3	45.78 (21.29)	46.37 (17.50)	0.58
ESSF 4	50.70 (7.52)	48.63 (7.53)	-2.07

Table 20. Results of mixed effects regression for lodgepole pine total height, stem diameter, and HDR.

	Height			Stem Diameter			HDR		
Variable	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)
Moisture	-0.46	3.35	0.890	-0.02	0.05	0.633	-0.08	0.29	0.783
N	-628.11	309.46	**0.042***	-8.46	4.68	0.070	-27.30	26.66	0.294
C	7.59	11.01	0.491	0.08	0.17	0.613	0.60	0.95	0.525
S	175.86	352.98	0.618	2.55	5.33	0.632	4.99	30.41	0.870
P	2.43	0.94	**0.010***	0.02	0.01	0.136	0.30	0.08	**0.000***
K	489.26	391.84	0.212	7.57	5.92	0.201	31.30	33.75	0.354
CEC	7.35	4.86	0.130	0.12	0.07	0.114	0.17	0.42	0.688
pH	32.21	30.87	0.297	-0.25	0.47	0.597	7.41	2.66	**0.005***
Bulk Density	210.02	89.33	**0.019***	3.01	1.35	**0.026***	12.82	7.70	0.096
Elevation	-2.26	1.26	0.073	-0.02	0.02	0.359	-0.27	0.11	**0.012***
Soil temp.	-182.97	111.60	0.101	-1.82	1.69	0.281	-16.66	9.61	0.083
LFH	-214.34	221.82	0.334	-3.58	3.35	0.285	-10.17	19.11	0.595
Slope	-2.20	1.38	0.112	-0.06	0.02	**0.004***	0.11	0.12	0.378
Clay	-6.44	6.23	0.301	0.08	0.09	0.383	-1.42	0.54	**0.008***
Random effects:									
Zone (SD)	1.66E-07			1.47E-12			3.20E-09		
Block (SD)	7.45E-08			6.05E-13			1.04E-09		
SD (residual)	80.2705			1.213096			6.914726		

* Significant at < 0.05

The Shapiro-Wilk test for normality showed biomass of destructively sampled pine seedlings (aboveground biomass $p = 0.000$, belowground biomass $p = 0.000$ and total biomass $p = 0.000$) were not normally distributed.

Height to diameter ratio changes were variable within blocks and zones. There was a negative change in BWBS 1 and 3 blocks, and both the BWBS and ESSF 4 blocks. The BWBS 2 block and the three upland ESSF blocks showed an increase in HDR between the two measurement years. An ANOVA test demonstrated that the differences in HDR was significant between biogeoclimatic zone ($F_{1, 330} = 137.96, p = 0.000$) and between blocks ($F_{3, 95} = 40.36, p = 0.000$).

In the BWBS upland blocks, greatest pine biomass was observed in the BWBS 2 block, while biomass in the 1 and 3 blocks was similar, and lowest biomass was found in the BWBS 4 block (Figure 31, Table 21, Table 22).

Table 21. Mean whole plant oven-dry biomass with standard error (reported in parentheses) of lodgepole pine seedlings (approximate age = 4 years at time of sampling in 2013) in upland blocks. BWBS 1 n = 8, BWBS 2 n = 8, BWBS 3 n = 8; ESSF 1 n = 8, ESSF 2 n = 8, ESSF 3 n = 8.

Block	Stems (g)	Needles (g)	Total aboveground (g)	Roots (g)	Total Biomass (g)
BWBS 1	4.32 (2.89)	4.72 (3.60)	9.04 (6.45)	2.41 (0.78)	11.45 (7.06)
BWBS 2	6.95 (5.53)	8.16 (6.29)	15.11 (6.45)	3.51 (1.87)	18.62 (13.48)
BWBS 3	4.95 (2.26)	4.80 (2.32)	9.75 (4.55)	2.25 (0.88)	12.00 (5.30)
ESSF 1	2.20 (1.26)	2.36 (1.64)	4.56 (2.84)	1.79 (1.15)	6.35 (3.85)
ESSF 2	9.72 (9.54)	12.92 (14.86)	22.64 (24.34)	5.21 (4.24)	27.86 (28.52)
ESSF 3	5.24 (5.21)	5.21 (4.96)	10.45 (10.09)	1.91 (1.36)	12.36 (11.35)

Table 22. Mean whole plant biomass with standard error (reported in parentheses) of lodgepole pine in wetland blocks. BWBS 4 n = 3, ESSF 4 n = 4.

Block	Stems (g)	Needles (g)	Total aboveground (g)	Roots (g)	Total Biomass (g)
BWBS 4	4.89 (2.82)	3.28 (3.03)	8.17 (5.84)	2.73 (1.83)	10.89 (7.59)
ESSF 4	1.74 (0.06)	1.21 (0.65)	2.95 (1.20)	1.20 (0.04)	4.16 (1.54)

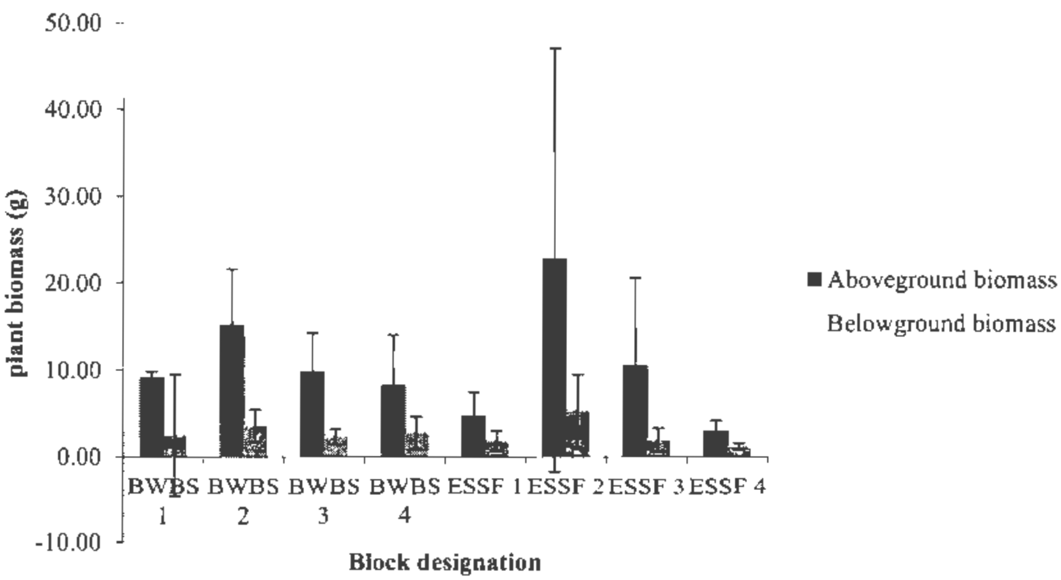


Figure 31. Mean above and below ground biomass with standard error of oven-dry lodgepole pine seedlings in all blocks. BWBS 1 n = 8, BWBS 2 n = 8, BWBS 3 n = 8, BWBS 4 n = 3; ESSF 1 n = 8, ESSF 2 n = 8, ESSF 3 n = 8, ESSF 4 n = 4.

The ANOVA for aboveground biomass showed that differences were not significant between zones ($F_{1,28} = 2.81$, $p = 0.094$), but were significant between blocks ($F_{3,8} = 38.57$, $p = 0.000$); and belowground biomass differences were significant between zones ($F_{1,28} = 4.55$, $p = 0.033$)

and blocks ($F_{3, 8} = 45.02, p = 0.000$). For total biomass, differences were not significant between zones ($F_{1, 28} = 3.09, p = 0.079$) but were significant between blocks ($F_{3, 8} = 39.74, p = 0.000$). In all BWBS blocks, most of the biomass was attributed to stems and needles. In the ESSF blocks, samples from the ESSF 2 block had more than double the biomass of the other upland blocks, and samples from the ESSF 3 block had almost double the biomass of the ESSF 1 block. Samples from the wetland block had the least biomass in the ESSF zone. Aboveground biomass in the ESSF upland blocks accounted for most (greater than eighty percent) of the total biomass, and needle biomass was greater than stem biomass (Table 21) in the ESSF 1 and 2 blocks than in the ESSF 3 block.

6.3.1.2 Shrubby Cinquefoil

Normality was achieved for height of cinquefoil ($p = .682$). Cinquefoil height was variable for upland blocks. Height was greatest in north-facing blocks and lowest in crest position blocks in both zones. ANOVA results showed that the differences in height by zone was not significant ($F_{1, 55} = 0.11, p = 0.746$); however, the differences by block were significant ($F_{3, 15} = 14.48, p = 0.000$). Results of the Tukey test showed significant differences in cinquefoil height between the wetland and south-facing blocks ($p = 0.026$), and between wetland and north-facing blocks ($p = 0.013$), while the means for seedlings in south-facing and north-facing blocks were similar (Figure 32).

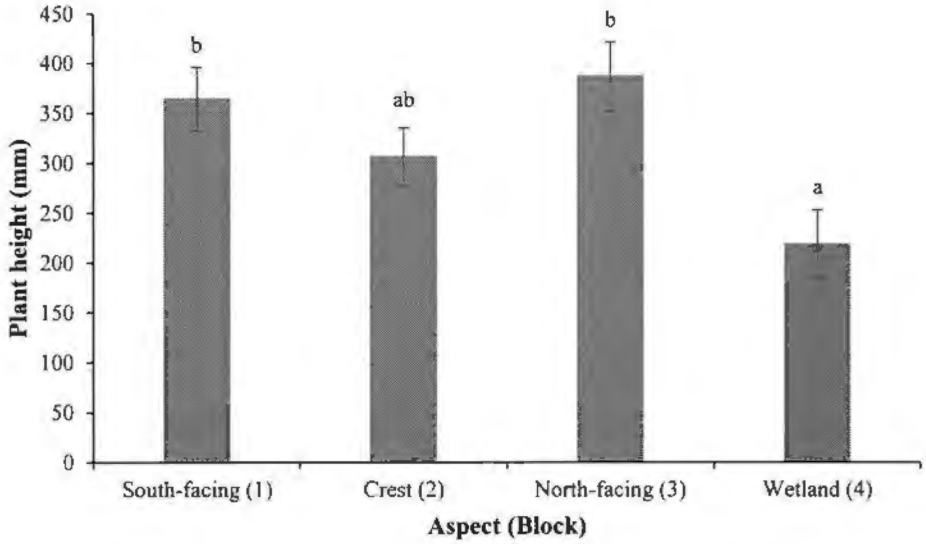


Figure 32. Mean and standard error of cinquefoil height by aspect (block). Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

Height values for each zone were lowest in the wetland blocks (BWBS 4, ESSF 4), and changes in height were smallest in each wetland block (Figure 33, Table 23, Table 24).

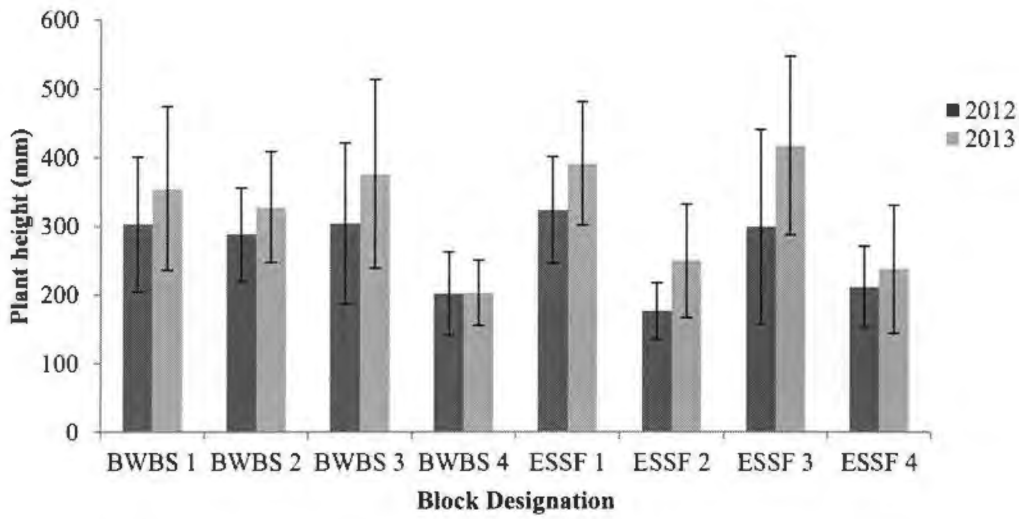


Figure 33. Mean plant height and standard error for 2012 and 2013 shrubby cinquefoil all blocks. BWBS 1 n = 14, BWBS 2 n = 15, BWBS 3 n = 14, BWBS 4 n = 9; ESSF 1 n = 16, ESSF 2 n = 14, ESSF 3 n = 13, ESSF 4 n = 15.

Cover area data were not normally distributed ($p = 0.021$) for cinquefoil. ANOVA results showed significant differences between blocks ($F_{3, 15} = 4.79, p = 0.013$) but not between zones ($F_{1, 55} = 0.21, p = 0.651$). The Tukey test returned significant differences between wetland and south-facing blocks ($p = 0.009$) (Figure 34).

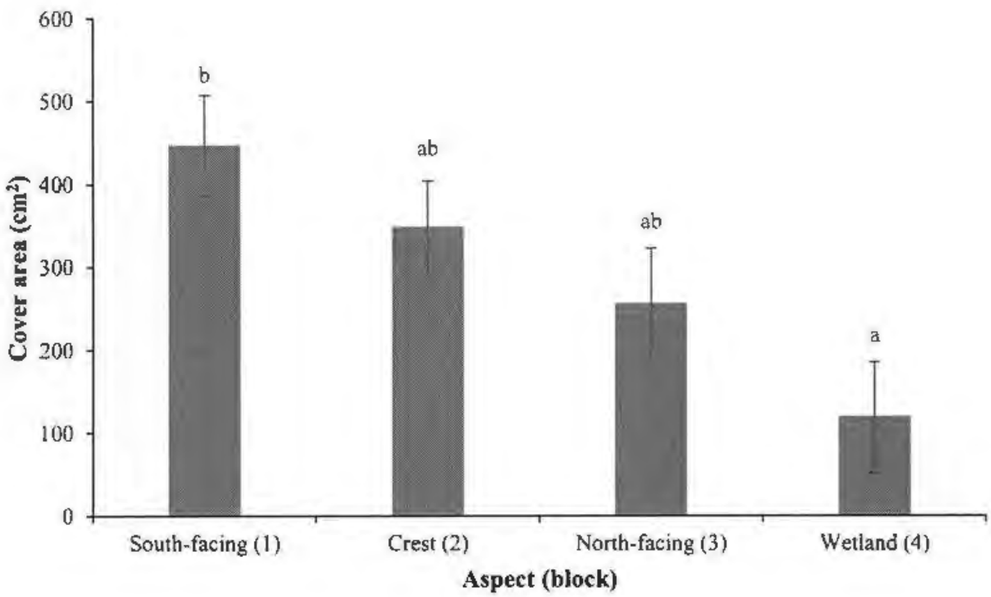


Figure 34. Mean and standard error of cinquefoil cover area by block. Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the $\alpha = 0.05$ level.

Cover area of cinquefoil differed in each block, highest cover area was noted in the BWBS 1 block, and the ESSF 2 block (Table 23). Differences in cover area were not significant by zone ($F_{1, 55} = 2.82, p = 0.096$), but were significant by block ($F_{3, 15} = 14.52, p = 0.000$). Cover area in wetland blocks was low, and changes in cover area between 2012 and 2013 were greater in the ESSF 4 block than the BWBS 4 block (Table 24).

The Wald chi^2 for cinquefoil height was 61.11 (prob > $chi^2 = 0.000$), and the Wald chi^2 was 68.60 (prob > $chi^2 = 0.000$) for cover area (Table 25). Species abundance, a key component of species diversity, was significant for plant height, while soil properties and topography were significantly correlated with cover area.

Normality was not achieved for aboveground biomass ($p = 0.000$), or for total biomass ($p = 0.005$), however it was achieved for belowground biomass ($p = 0.077$). Cinquefoil displayed higher allocation of biomass to aboveground stems and leaves in xeric blocks, and higher biomass allocation to roots in the BWBS 4 block (average BWBS 59%, ESSF 53 %) (Table 27 and 28). The differences in aboveground biomass by block were significant ($F_{3,3} = 19.68$, $p = 0.000$). By zone, average total biomass for the BWBS 4 block was lower (7.58 g) per block than upland blocks, and differences in aboveground biomass were significant by zone ($F_{1,22} = 22.89$, $p = 0.000$). Belowground biomass in upland blocks was lowest in BWBS and ESSF 3 blocks, and highest in BWBS and ESSF 2 blocks, however the differences were not significant by zone ($F_{1,22} = 1.09$, $p = 0.310$), but were significant by block ($F_{3,3} = 3.85$, $p = 0.027$). Despite the differences in biomass between block, they were not statistically significant (Figure 35).

Table 23. Mean plant height and cover area (standard error reported in parentheses) for 2012 and 2013 with interannual change, shrubby cinquefoil upland blocks. BWBS 1 n = 14, BWBS 2 n = 15, BWBS 3 n = 14; ESSF 1 n = 16, ESSF 2 n = 14, ESSF 3 n = 13.

	2012		2013		Interannual change	
Block	Height (mm)	Cover area (cm^2)	Height (mm)	Cover area (cm^2)	Height (mm)	Cover area (cm^2)
BWBS 1	302.80 (98.30)	320.67 (124.55)	355.00 (119.49)	376.78 (185.94)	52.2	56.12
BWBS 2	288.00 (68.86)	154.73 (102.91)	328.00 (81.17)	340.68 (254.51)	40	185.95
BWBS 3	304.00 (117.65)	84.93 (48.80)	375.71 (137.39)	204.77 (135.94)	71.71	119.84
ESSF 1	323.44 (78.15)	114.33 (227.11)	391.33 (89.63)	140.82 (281.48)	67.9	26.49
ESSF 2	176.29 (40.80)	113.48 (90.00)	249.79 (83.78)	388.48 (326.84)	73.5	275
ESSF 3	299.23 (141.65)	243.46 (224.05)	416.54 (129.93)	221.15 (179.43)	117.31	-22.31

Table 24. Mean plant height and cover area (standard error reported in parentheses) with interannual change shrubby cinquefoil wetland blocks. BWBS 4 n = 9, ESSF 4 n = 15.

	2012		2013		Interannual change	
Block	Height (mm)	Cover area (cm^2)	Height (mm)	Cover area (cm^2)	Height (mm)	Cover area (cm^2)
BWBS 4	201.78 (60.99)	84.19 (39.71)	203.33 (47.30)	113.17 (50.19)	1.56	28.97
ESSF 4	211.00 (59.59)	74.42 (24.57)	238.20 (93.76)	126.37 (50.76)	27.2	51.95

Table 25. Hierarchical regression of cinquefoil height and cover area.

	Height			Cover Area		
Variable	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)
Moisture	-22.55	19.19	0.240	-14298.56	4120.28	**0.001***
N	-4128.78	2970.72	0.165	-426743.60	637860.20	0.503
C	128.88	73.17	0.078	3593.57	15710.58	0.819
S	-4399.61	1325.05	**0.001***	-1384259.00	284508.30	**0.000***
P	-1.20	12.40	0.923	-1265.66	2662.80	0.635
K	874.98	709.47	0.217	305762.70	152333.60	0.045
CEC	27.82	23.59	0.238	10356.42	5064.39	**0.041***
pH	58.38	77.15	0.449	30097.88	16564.67	0.069
Bulk Density	516.53	218.74	**0.018***	149556.30	46996.95	**0.001***
Elevation	-0.91	3.87	0.815	-1818.96	830.58	**0.029***
Soil temp.	-319.99	364.25	0.380	-215654.50	78209.91	**0.006***
LFH	-39.97	944.25	0.966	-332488.20	202745.80	0.101
Slope	1.22	2.60	0.638	-312.88	557.29	0.575
Clay	5.99	28.32	0.832	3411.29	6080.28	0.575
Random effects:						
Zone (SD)	1.33E-07			0.0000613		
Block (SD)	2.66E-08			1.18E-05		
SD (residual)	89.71543			19263.31		

* Significant at < 0.05

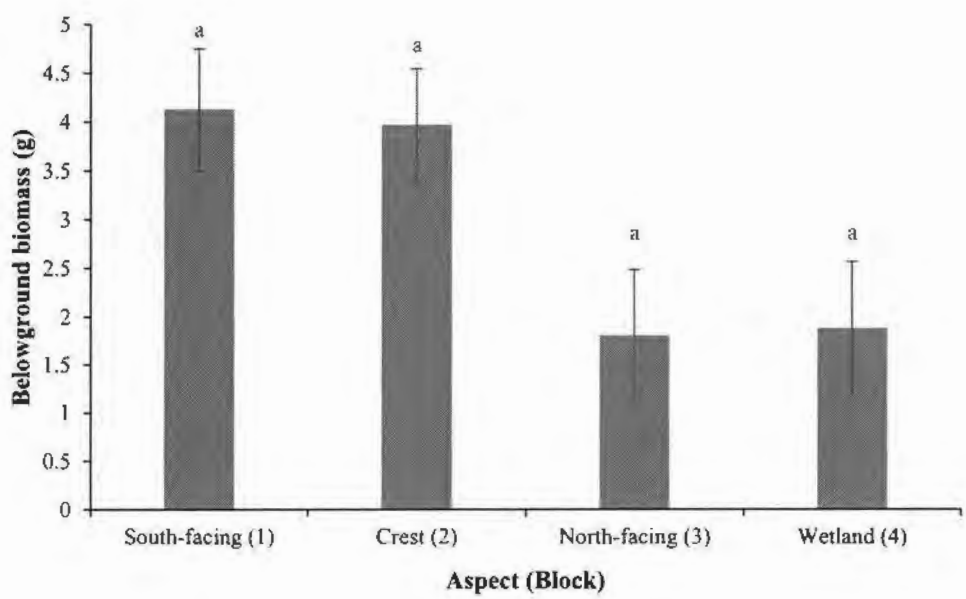


Figure 35. Mean and standard error of belowground (root) biomass by block. Numbers in parentheses represent block designation. Letters indicate Tukey results, and means sharing a letter were not significantly different at the α = 0.05 level.

The lowest average biomass of cinquefoil seedlings in the ESSF zone upland blocks was the ESSF 3 block, which had an average biomass of 10.11 g (Table 27). Total mean biomass of samples from the ESSF 4 block had the lowest average for the zones (Table 27). Total biomass values were significantly different by zone ($F_{1, 12} = 26.48$, $p = 0.000$) and by block ($F_{3, 3} = 22.62$, $p = 0.000$).

Table 26. Means and standard error (reported in parentheses) of whole plant oven-dry biomass shrubby cinquefoil in upland blocks. BWBS 1 n = 3, BWBS 2 n = 3, BWBS 3 n = 3; ESSF 1 n = 3, ESSF 2 n = 3, ESSF 3 n = 3.

Block	Stems (g)	Leaves (g)	Total aboveground (g)	Roots (g)	Total Biomass (g)
BWBS 1	5.39 (1.48)	1.80 (0.65)	7.19 (2.13)	3.69 (0.88)	10.88 (2.95)
BWBS 2	4.14 (3.07)	1.39 (0.91)	5.53 (3.98)	4.16 (1.24)	9.69 (4.69)
BWBS 3	1.35 (0.92)	0.27 (0.19)	1.62 (1.07)	1.14 (0.26)	2.76 (1.14)
ESSF 1	7.62 (6.82)	2.65 (1.93)	10.27 (8.63)	4.55 (2.35)	14.82 (10.90)
ESSF 2	3.48 (1.38)	1.96 (1.18)	5.44 (2.54)	4.67 (1.87)	10.11 (4.40)
ESSF 3	5.24 (7.20)	1.10 (1.66)	6.34 (8.86)	2.25 (2.14)	8.59 (11.00)

Table 27. Means and standard error (reported in parentheses) of whole plant biomass shrubby cinquefoil in wetland blocks. BWBS 4 n = 2, ESSF 4 n = 3.

Block	Stems (g)	Leaves (g)	Total aboveground (g)	Roots (g)	Total Biomass (g)
BWBS 4	0.81 (0.60)	0.32 (0.30)	1.13 (0.90)	1.28 (0.26)	2.41 (1.16)
ESSF 4	2.05 (0.51)	0.62 (0.21)	2.67 (0.70)	2.26 (0.52)	4.93 (0.41)

Total biomass ANOVA for shrubby cinquefoil showed that there were no significant differences between blocks ($F_{3, 3} = 2.25$, $p = 0.118$) or zones ($F_{1, 12} = 1.43$, $p = 0.247$). Mixed effects regressions were performed for aboveground, belowground, and total biomass of shrubby cinquefoil (Table 28). Aboveground biomass regression Wald chi^2 was 671.39 (prob > chi^2 = 0.000). Results for belowground biomass Wald chi^2 was 626.20 (prob > chi^2 = 0.000). Total biomass Wald chi^2 was 791.55 (prob > chi^2 = 0.000).

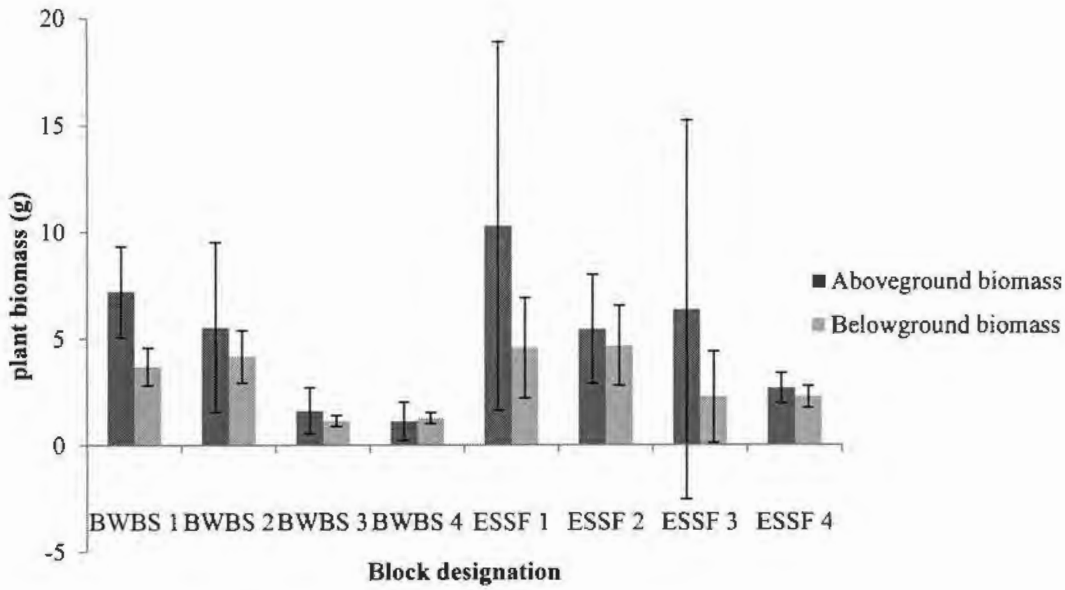


Figure 36. Mean above and belowground plant biomass shrubby cinquefoil all blocks. BWBS 1 n = 3, BWBS 2 n = 3, BWBS 3 n = 3, BWBS 4 n = 2; ESSF 1 n = 3, ESSF 2 n = 3, ESSF 3 n = 3, ESSF 4 n = 3.

Table 28. Hierarchical regression for cinquefoil biomass (aboveground, belowground, and total biomass).

	Aboveground			Belowground			Total		
Variable	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)	β	β SE	p (< 0.05)
Moisture	-0.91	0.33	**0.006***	-0.56	0.15	**0.000***	-1.55	0.51	**0.002***
N	347.77	62.40	**0.000***	11.13	22.56	0.622	183.06	78.81	**0.020***
C	-9.82	1.59	**0.000***	-0.37	0.56	0.515	-5.41	1.94	**0.005***
S	-474.44	23.25	**0.000***	-130.11	10.06	**0.000***	-583.47	35.15	**0.000***
P	-0.29	0.21	0.172	0.12	0.09	0.222	-0.13	0.33	0.687
K	77.07	13.17	**0.000***	21.13	5.39	**0.000***	122.2	18.82	**0.000***
CEC	-0.45	0.44	0.308	0.28	0.18	0.125	0.62	0.63	0.325
pH	10.70	1.34	**0.000***	3.26	0.59	**0.000***	14.93	2.05	**.000***
Bulk Density	29.02	4.33	**0.000***	11.04	1.66	**0.000***	50.56	5.8	**.000***
Elevation	-0.55	0.13	**0.000***	-0.08	0.03	**0.005***	-0.46	0.1	**.000***
Soil temp.	-60.85	11.48	**0.000***	-11.16	2.77	**0.000***	-62.84	9.66	**.000***
LFH	-156.86	27.10	**0.000***	-18.53	7.17	**0.010***	-138.17	25.05	**.000***
Slope	0.44	0.15	**0.003***	0.03	0.02	0.192	0.34	0.07	**.000***
Clay	5.03	0.57	**0.000***	0.53	0.22	**0.014***	4.13	0.75	**.000***
Random effects:									
Zone (SD)	2.33E-08			8.57E-11			1.61E-11		
Block (SD)	3.15E+00			8.74E-12			1.74E-10		
SD (residual)	1.55			0.6813203			2.380049		

* Significant at < 0.05

6.3.1.3 Plant Mortality

Plant mortality of lodgepole pine varied between zones (Figure 37). Normality of pine mortality was not achieved at $\alpha = 0.05$ ($p = 0.003$). Differences in mortality between zones were significant ($F_{1,22} = 29.46$, $p = 0.000$), but not between blocks ($F_{3,22} = 0.80$, $p = 0.499$). The results from the Tukey test found that differences observed between zones was significant ($p = 0.000$), however, a lettered group option could not be generated as there was only one comparison between zones.

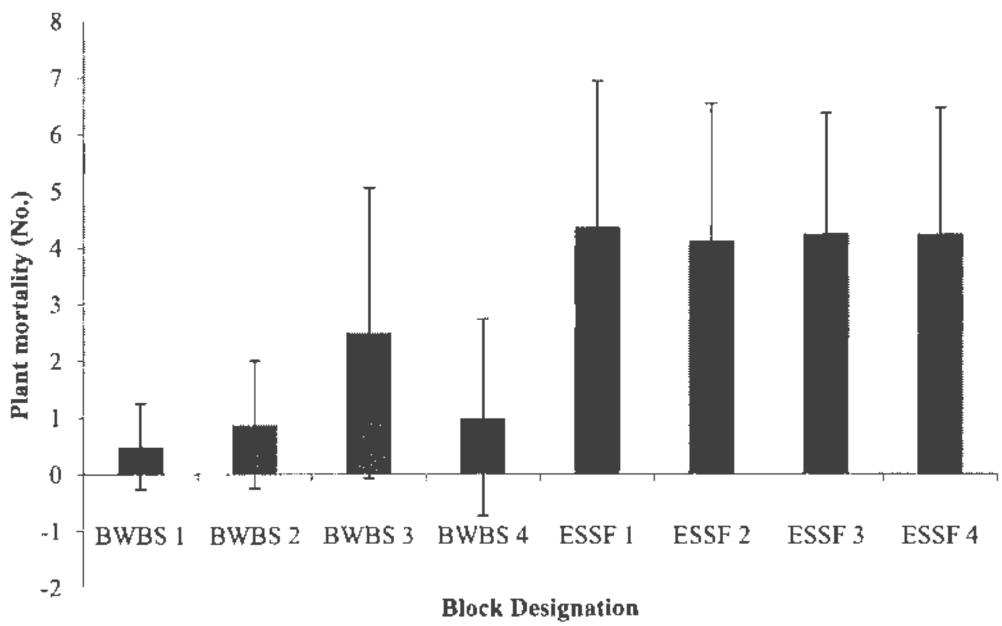


Figure 37. Lodgepole pine seedling mortality (mean and SE) in all blocks. In 2013, the numbers of surviving seedlings per block were: BWBS 1 n = 96, BWBS 2 n = 94, BWBS 3 n = 80, BWBS 4 n = 37*; ESSF 1 n = 62, ESSF 2 n = 66, ESSF 3 n = 68, ESSF 4 n = 43.
*BWBS 4 numbers exclude 15 seedlings in the Pl c plot, which was disregarded due to ongoing human disturbance.

Three hundred and seventy seedlings were planted in summer 2010 in the BWBS zone, and another three hundred and seventy seedlings were planted in the ESSF zone. By end of summer 2013, there were three hundred and seven individuals in BWBS plots, and two hundred and thirty-nine individuals in ESSF plots. The mortality in the BWBS zone occurred between planting and the first year of measurements. Mean mortality within the BWBS upland blocks was less than observations of mortality in ESSF upland blocks. Similarly, mean mortality in the BWBS 4 block was less than that at the ESSF 4 block. Mortality in the "Pl c" lodgepole pine plot in BWBS 4 was excluded as the plot was ahandoned due to continued human disturbance.

6.4 Discussion

Plant growth and biomass differed between blocks for both lodgepole pine and shrubby cinquefoil. Some results were supported by other research; however other findings were contradictory to other works on plant growth. The findings of this study suggest that optimal growth for both species considered was not observed in sites with hydric soils, and other plant species should be considered in wetland reclamation.

6.4.1 Plant Height and Biomass

Lodgepole pine seedlings responded differentially to block soil properties. Total height was highest in BWBS and ESSF 3 blocks, yet total biomass was greatest in BWBS and ESSF 2 blocks. Shrubby cinquefoil heights were greatest in BWBS and ESSF 3 blocks, however total biomass was greatest in BWBS and ESSF 1 blocks.

6.4.1.1 Lodgepole Pine

Growth of pine seedlings between 2012 and 2013 was variable between blocks, between plots, and within plots. Height of pine seedlings in the ESSF 2 block was the most variable, and mean plant height was greatest in this block. Soil factors were a significant factor in this zone, in particular for the ESSF 2 and 3 blocks. It is possible that naturally occurring species such as fireweed and willow saplings played a role in improved survival and growth of pine seedlings in tbe ESSF 2 block, as Castro et al. (2004) demonstrated with the use of shrubs as nurse plants. For the ESSF 2 block, the mean height of seedlings was higher where species diversity was greater.

Average soil moisture values were lowest at the crest position site, where changes in plant height were highest between 2012 and 2013, which supports prior research that found a preference of lodgepole pine for xeric soils (Despain 2001) although other factors not considered in this analysis may also contribute to plant height.

Lodgepole pine biomass in the BWBS 4 block was greater for aboveground than belowground. Other research has noted greater accumulation of aboveground biomass in lodgepole pine in moist (mesic) sites (Comeau and Kimmins 1989) related to older trees, but this association could also be important for seedlings in saturated (hygric to hydric) conditions.

Hierarchical regression of pine biomass showed slope was significantly correlated with pine biomass. Slope was a confounding factor in pine biomass, as biomass was greatest for both biogeoclimatic zones in south-facing blocks (seven percent slope in BWBS 1, and thirty percent slope in ESSF 1), however pine biomass was lowest in the BWBS and ESSF 3 blocks (twelve percent slope in BWBS 3 and twenty-two percent slope in ESSF 3).

Factors affecting lodgepole pine height in BWBS upland blocks were not consistent between blocks. Bulk density was positively correlated to plant height in BWBS 1, CEC was significant (positive correlation) in BWBS 2, and moisture was significant (negative correlation) in BWBS 3. Average aboveground biomass at the BWBS blocks was greatest for upland positions. This contrasts the findings of Comeau and Kimmins (1989), who noted a higher proportion of biomass allocation to belowground biomass on drier sites, and higher allocation of biomass to aboveground production on mesic sites.

Pine allometry considered in this study (total height, stem diameter, and HDR) was, according to the hierarchical regression model, significantly ($p < 0.05$) affected by total N (total height), available P (total height and HDR), bulk density (total height and stem diameter), and for HDR only, pH, elevation, and clay percentage. In this study, N was negatively associated with height as the sites higher in N content were north-facing blocks and wetlands, where mean plant height was lowest; which contrasts with other findings regarding N levels and forest productivity, where higher N values were positively correlated with plant height (Simard *et al.* 2003). Some research has found that the effectiveness of N additions can be compromised by S (Brockley 2000), and the total S was higher in both wetland blocks. It is more likely that poor plant performance in wetlands was due to lower tolerance of lodgepole pine to hydric soils.

Available P values were higher in ESSF upland blocks than the BWBS upland and both wetland blocks. The relationship between P and pine height was positive, however this does not adequately address the height parameter, as seedlings were taller in the BWBS upland blocks. Soil bulk density was positively correlated with height and stem diameter; increased bulk density was associated with increased height and diameter. The lowest bulk density values were observed in wetlands, where plant growth was lowest, and high bulk densities were noted in upland blocks, although means were less than the critical density where adverse effects to plant growth in a medium textured soil (> 1.40 g cm^{-3}) are apparent. Growth of lodgepole pine was not adversely affected by high soil bulk density in this study, and this has been observed in other lodgepole pine studies (Zabowski *et al.* 2000; Kranabetter *et al.* 2006).

6.4.1.2 Shrubby Cinquefoil

Height of shrubby cinquefoil varied widely in the ESSF upland blocks, and the tallest seedlings were noted in the ESSF 3 block, and lowest in the ESSF 2 block. The regression output did not adequately determine significant factors, although seedling density (species abundance) was determined significant ($p = 0.019$); total nitrogen, sulphur, potassium, and CEC values were higher in ESSF 3 than ESSF 2, however soil temperature was lower in ESSF 3, and moisture values in 2013 were similar between upland blocks. None of these factors were found to be significant in the regression of data for the entire study area, although replication of blocks for slope aspect could have helped understand if these variables were significant between the ESSF 2 block and the ESSF 3 block.

Biomass of shrubby cinquefoil in the ESSF upland blocks was highest in the ESSF 1 block, and lowest in the ESSF 2 block, although variability in ESSF 1 was higher. Aboveground biomass accounted for more total biomass than belowground in all upland blocks, but was greatest in ESSF 1 and ESSF 3. With the exception of slope and species abundance, all factors considered for analysis were significant for aboveground, belowground and total biomass. Notably, total carbon, total sulphur, CEC, and species richness were negatively correlated with the three biomass parameters. The effects of these by block could not be determined, and the influence of soil nutrients on biomass may have been skewed by the high values in the ESSF 4 block which had considerably higher nutrient contents than the upland ESSF blocks.

Nutrition and CEC values for the ESSF 4 block indicated high potential productivity. The soil moisture regime of this block was classified as hydric, because soil moisture levels were consistently around 100%. Total carbon was negatively correlated with plant height in this block, and mean height of plants was low. Total biomass of lodgepole pine was the lowest of the blocks; mortality was moderate, and comparable with ESSF upland blocks.

Cinquefoil growth by changes in height between 2012 and 2013 was minimal ($\Delta = 12.20$ mm) in the BWBS 4 block. Shrubby cinquefoil is a commonly found species in fen environments (Pojar 1991; Drahovzal *et al.* 2015), although its suitability as a wetland plant may not be universal

(Niswander and Mitsch 1995). One of the factors that could have affected cinquefoil growth in BWBS 4 was the prevalence of bluejoint (*Calamagrostis canadensis*). This species can be hypercompetitive in disturbed sites, has been demonstrated to adversely affect some plant species growth (Matsushima *et al.* 2014), and was the dominant naturally regenerated species in this block. However, the correlation between shrubby cinquefoil with richness was negative hut not significant, and the correlation with abundance was positive, so this was not a conclusive factor.

Biomass of shrubby cinquefoil was primarily allocated to belowground in BWBS 4. This finding is consistent with other research that suggested greater root than shoot biomass production in shrubby cinquefoil and other alpine shrubs (Long 2003) in wetland environments. Biomass of shrubby cinquefoil seedlings was negatively affected by total carbon, sulphur, CEC and species richness; however, the relationship of these properties to biomass in the wetland block could not be directly related.

Mixed effects regression results for cinquefoil height showed that soil S and bulk density affected height significantly. Sulphur values were highest in BWBS and ESSF 3 and 4 blocks, and bulk density values were lowest in the BWBS and ESSF 3 and 4 blocks. Height of shrubby cinquefoil seedlings was greatest in BWBS and ESSF 3 blocks. Height averages were lowest in wetlands, and for uplands plant height was lowest at BWBS and ESSF 2 blocks; soil moisture was not a significant contributor to plant height.

Cover area of shrubby cinquefoil was significantly influenced by soil moisture, S, CEC, bulk density, elevation, and soil temperature. Soil moisture was negatively correlated with cover area, and cover area means were greatest in blocks where the lowest soil moisture averages were observed (21.66 % in BWBS 1, and 21.31 % in ESSF 2 block) for each biogeoclimatic zone. Shrubby cinquefoil grows in a variety of soil moisture conditions; the results of this study suggest that the cover area growth component performs better in well drained soils in northeastern B.C.

Shrubby cinquefoil biomass was significantly impacted by all of the variables considered except available P and effective CEC. Low biomass was correlated with higher soil moisture, observed in BWBS 3 and both BWBS and ESSF 4 blocks. In upland blocks, greatest biomass averages were in BWBS and ESSF 1 blocks (10.88 g in BWBS 1, 14.82 g in ESSF 1). Soil C and soil S were negatively associated with cinquefoil biomass, and the mean values of C and S were highest in BWBS and ESSF 3 and 4 blocks. This does not account for the positive correlation between biomass and N, mean values for which were also highest in north-facing and wetland blocks. Elevation was significantly negatively correlated with biomass; this association is not definitive, as the ESSF 4 block was at a lower elevation than the ESSF 3 block, where highest biomass was observed. The values of bulk density and soil pH were not consistently higher in either the BWBS or ESSF 1 blocks. The regression model correlated a positive significant relationship between increased slope and increased cinquefoil biomass, however the ESSF 3 block had the lowest biomass, but the highest slope percentage (thirty percent).

6.4.2 Plant Survival

Pine losses were apparent between planting in 2010 and last measurements in 2013. There was not an appreciable difference between mortality in upland and wetland blocks in either zone. The difference in losses between the BWBS and ESSF zones could be attributed to a number of factors. Desiccation at sites exposed to wind had a negative influence on survival. The south facing and crest position sites also had less natural regeneration, reflected by low species richness and diversity of colonizer species within treatment and control plots. Elevation was also a factor for lodgepole pine mortality, with higher mortality in the ESSF zone, where the blocks were above 1260 m.a.s.l.; the generally accepted elevation limit for lodgepole pine in northern B.C. is 1200m (Rehfeldt *et al.* 1999).

Cinquefoil losses were not observed during the study period, findings consistent with other research that found high survival (93-100%) of cinquefoil seedlings in a variety of growing conditions (Densmore and Holmes 1987). This species tolerates a wide variety of ecological conditions and can be persistent in disturbed environments (Elkington and Woodell 1963). Given the tenacity of shrubby cinquefoil as a colonizer species, and as it has low forage values for wildlife, the high survival rates of seedlings at the study site are likely typical. At crest and south-facing blocks, cinquefoil seedlings were occasionally the only surviving species observed within cinquefoil plots. Planting density may have been a factor, combined with environmental influences.

Pine mortality regression showed that only effective CEC was significant among the variables considered for seedling mortality. The relationship was positive, implying that increased CEC was correlated with increased mortality. This was evident in the BWBS 3 block and the ESSF 4 block, but does not explain high mortality in ESSF upland blocks, where CEC was low, and mortality was comparable (4.125 to 4.375 plants per block) between blocks. In the ESSF upland blocks, there was evidence, which could not be captured, of seedling desiccation from wind exposure in the south-facing and crest blocks, and small scale mechanical erosion in the ESSF 3 block.

6.4.3 Limitations

As this was a retrospective study, controls for lodgepole pine could not be established, which may have shown differences in mortality, growth, and biomass between fertilized and unfertilized seedlings for each upland block. Limited resources prevented foliar analysis of destructively sampled seedlings, which could have demonstrated N uptake in plants. Weather stations that capture wind variables were not established, which could have helped associate prevailing winds with plant establishment, specifically for lodgepole pine. The ecologically short time frame of the field components of this study did not allow for determining the potential effects of time for changes in plant growth and ongoing mortality of seedlings as they mature.

6.5 Conclusion

The primary aim of this study was to observe the response of two plant species planted at sites where whole tree harvest and substrate disturbance had occurred for installation of pipeline assets in northeastern British Columbia. The results of this study showed that lodgepole pine experienced higher mortality in the ESSF biogeoclimatic zone, and that there was greater variation in plant biomass between upland blocks in the ESSF zone than those in the BWBS zone. There were no observed shrubby cinquefoil losses during the study period, and biomass was greater for plants sampled from upland blocks in the ESSF zone than upland blocks in the BWBS zone.

Future studies and reclamation projects for northeastern B.C. located in the BWBS and ESSF biogeoclimatic zones should consider using native plant species best suited to site conditions. The growth of plant species monitored in this study in upland sites suggests that lodgepole pine and shrubby cinquefoil are suitable for uplands, although elevation and other factors may compromise lodgepole pine survival. In wetlands however, use of vascular plant species that thrive in wet soils would be preferable.

The results of this study showed that field performance of lodgepole pine was acceptable, however, mortality rates were higher in the ESSF upland blocks than BWBS upland blocks. Likewise, cinquefoil field performance was adequate, although biomass was greater in ESSF upland blocks. Both planted species grew more slowly in wetland blocks, which infers that species options should be altered for hydric soils. There are opportunities to use other native species in wetlands, which could be based on locally abundant native plants. Meaningful input from local First Nations communities would help foster positive relationships between stakeholders and could also help guide plant species deployment in reclaimed right-of-ways that include traditional foods and medicinal plants.

7.0 Synthesis of Results

This research was commissioned by Shell Canada with a purpose to understand the soil properties that influence the establishment and growth of plants on a reclaimed pipeline right-of-way in northeastern B.C. Methods included soil sampling of physical and chemical properties, plant community development within control and planted plots at each research block, assessed using the Shannon Diversity Index; and plant measurements used to determine field performance of planted lodgepole pine and shrubby cinquefoil seedlings. Results are found in the preceding chapters, however, soil physical and chemical properties showed low percentages of plant available nutrients in south-facing and crest position blocks, and highest in wetland blocks. Plant species diversity was highest in wetland blocks, and lowest in crest position blocks in both biogeoclimatic zones. Treatment and slope aspect were significant in species diversity values. Slope aspect was also influential in plant growth and biomass observations, although the effects on height and biomass were not directly correlated.

Limitations of this study included lack of true replicates in the experimental design, which resulted in pseudoreplication, and the short time frame of the study which may not have captured site recovery potential. The wind variable was not captured, which could have furthered our understanding of the effects of wind to site recovery and seedling field performance. The difference in time since initial disturbance between wetland research blocks may have contributed to the differences in species diversity between the two wetland blocks in this study.

The significance of the findings to reclamation of pipeline rights-of-way in northeastern B.C. include the value of retention and careful replacement of soil horizons over pipe trenches; and that CWD application is beneficial to soil properties. Our results demonstrated that prescriptive planting can enhance natural regeneration and improve plant species diversity on a pipeline right-of-way. Plant growth findings noted less height accumulation and higher mortality of lodgepole pine seedlings in the ESSF biogeoclimatic zone than the BWBS biogeoclimatic zone; and variable biomass allocation to aboveground and belowground. The ESSF biogeoclimatic zone in northeastern B.C. includes challenging conditions for plant growth, which may be compounded by the effects of pipeline right-of-way construction in this region.

For future projects, industry should retain CWD wherever possible, as it traps leaf litter and contributes to higher soil chemical properties. Based on our research, natural regeneration is not an optimal strategy in BWBS and ESSF zones in northeastern B.C. and planting programs are strongly recommended to enhance site recovery. It is strongly recommended that industry and reclamation practitioners apply appropriate plant species in upland and wetland sites, which reduces plant losses and the need for costly replanting. Industry should also involve stakeholders (community groups, First Nations, research institutions) prior to commencement of a reclamation project. This would help foster positive relationships with local communities and First Nations people, and provide ideas for planting culturally important native plant species. The inclusion of research institutions would improve the scientific rigour of reclamation trials that can provide directions for future site management. This would help with site recovery, and provide tools for site assessment requirements needed by industry to apply for a Certificate of Restoration from the regulator in B.C. There is also a need to understand plant and wildlife interactions, and research that examines the interactions would be very beneficial in northeastern B.C.

Literature Cited

Agriculture and Agri-Food Canada [Internet]. 2010. Ch. 15: Soil phase. Canadian System of Soil Classification 3rd edn. Government of Canada. Ottawa [ON]. Available from: http://sis.agr.gc.ca/cansis/taxa/cssc3/chpt15.html

Al-Kayssi AW, Al-Karaghouli AA, Hasson AM, Beker SA. 1990. Influence of soil moisture content on soil temperature and heat storage under greenhouse conditions. J. Agric. Eng. Res. 45: 241-252.

Ampontuah EO, Robinson JS, Nortcliff S. Assessment of soil particle redistribution on two contrasting cultivated hillslopes. Geoderma 132 (3-4): 324-343.

Angell AC, Parkins JR. 2011. Resource development and aboriginal culture in the Canadian north. Polar Rec. 27 (240): 67-79.

Astrom M, Dynesius M, Hylander K, Nilsson C. 2007. Slope aspect modifies community responses to clear-cutting in boreal forests. Ecology 88 (3): 749-758.

Baker DC, McLelland JN. 2003. Evaluating the effectiveness of British Columbia's environmental assessment process for first nations' participation in mining development. Environ. Imp. Assess. Rev. 23 (5): 581-603.

Ballard TM 1980. Tree nutrition. Proceedings: workshop on reconstruction of forest soils in reclamation. April 8-9, 1980. Edmonton (AB). RRTAC 80-4. Alberta conservation and reclamation council. pp 9-21.

Ballard TM. 2000. Impacts of forest management on northern forest soils. For. Ecol. Manage. 133 (1-2): 37-42.

Barbier S, Gosselin F, Batandier P. 2008. Influence of tree species on understory vegetation diversity and mechanisms involved- a critical review for temperate and boreal forests. For. Ecol. Manage. 254 (1): 1-15.

Barbour MG, Burk JH, Pitts WD. 1987. Ch. 7. Commensalism, protocooperation, mutualism and herbivory. Terrestrial plant ecology. 2nd edition. California: Benjamin/Cummings. pp. 133-154.

Barbour MG, Burk JH, Pitts WD. 1987. Ch. 8. Community concepts and attributes. Terrestrial plant ecology. 2nd edition. California: Benjamin/Cummings. pp. 156-181.

Barbour MG, Burk JH, Pitts WD. 1987. Ch. 13. Mineral cycles. Terrestrial plant ecology. 2nd edition. California: Benjamin/Cummings. p. 294-324.

Barbour MG, Burk JH, Pitts WD. 1987. Ch. 14. Light and temperature. Terrestrial plant ecology. 2nd edition. California: Benjamin/Cummings. pp. 326-355.

Barbour MG, Burk JH, Pitts WD. 1987. Ch. 20. Major vegetation types of North America. Terrestrial plant ecology. 2nd edition. California: Benjamin/Cummings. p. 486-567.

Bartels SF, Chen HYH. 2010. Is understory plant species diversity driven by resource quantity or resource heterogeneity? Ecology 91 (7): 1931-1938.

Berger AL, Puettmann KJ. 2000. Overstory composition and stand structure influence herbaceous plant diversity in the mixed aspen forest of northern Minnesota. Amer. Mid. Nat. 143 (1): 111-125.

Bergeron Y, Harvey B, Leduc A, Gauthier S. 1999. Forest management guidelines based on natural disturbance dynamics: stand and forest-level considerations. For. Chron. 75 (1): 49-54.

Berli M, Kulli B, Attinger W, Leuenberger J, Flühler H, Springman SM, Schulin R. 2004. Compaction of agricultural and forest subsoils by tracked heavy construction machinery. Soil Till. Res. 75 (1): 37-52.

Blanco H, Lal R. 2008. Ch. 1. Soil and water conservation. In: Blanco H, Lal R. editors. Principles of soil conservation and management. New York [NY] Springer. p 1-18.

Bobbink P, Hicks K, Galloway J, Spranger T, Alkemade R, Ashmore M, Bustamante M, Cinderby S, Davidson E, Dentener F, Emmett B, Erisman J-W, Fenn M, Gilliam F, Nordin A, Pardo L, DeVries W. 2010. Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. Ecol. Appl. 20 (1): 30-59.

Bobiec A. 2002. Living stands and dead wood in the Bialowieża forest: suggestions for restoration management. For. Ecol. Manage. 165 (1-3): 125-140.

Booth AL, Skelton NW. 2011. Industry and government perspectives on first nations' participation in the British Columbia environmental assessment process. Environ. Imp. Assess. Rev. 31 (3): 216-225.

Bose AK, Harvey BD, Brais S, Beaudet M, Leduc A. 2014. Constraints to partial cutting in the boreal forest of Canada in the context of natural disturbance-based management: a review. For. 87 (1): 11-28.

Brady NC, Weil RR. 1996. Ch 5. Soil water: characteristics and behaviour. The nature and properties of soils. 11th edn. Upper Saddle River (NJ). Prentice-Hall. pp 144-175.

Brady NC, Weil RR. 1996. Ch 14. Soil phosphorus and potassium. The nature and properties of soils. 11th edition. New Jersey: Prentice Hall. p 445-87.

Brady NC, Weil RR. 2002. Ch 8. Soil colloids: seat of chemical and physical activity. The nature and properties of soils. 13th edition. New Jersey: Prentice Hall. p 316-62.

Brady NC, Weil RR. 2008. Ch. 1. The soils around us. The nature and properties of soils. 14th rev. edn. Upper Saddle River (NJ). Prentice-Hall. pp 2-31.

Brady NC, Weil RR. 2008. Ch 13. Nitrogen and sulfur economy of soils. The nature and properties of soils. 14th rev. edition. New Jersey: Prentice Hall. p 543-91.

Brandt JP. 2009. The extent of the North American boreal zone. Environ. Rev. 17: 101–161.

Brassard BW, Chen HYH. 2008. Effects of forest type and disturbance on diversity of coarse woody debris in boreal forest. Ecosystems 11 (7): 1078-1090.

Bridgham SD, Faulkner SP, Richardson CJ. 1991. Steel rod oxidation as a hydrologic indicator in wetland soils. Soil Sci. Soc. Amer. J. 55 (3): 856-682.

Bridgham SD, Megonigal JP, Keller JK, Bliss NB, Trettin C. 2006. The carbon balance of North American wetlands. Wetlands 26 (4): 889-916.

[BCMEM] BC Ministry of Energy and Mines [Internet] 2012. British Columbia's natural gas strategy: fuelling BC's economy for the next decade and beyond. Government of British Columbia. Victoria [BC]. Available from: http://www.gov.bc.ca/ener/popt/down/natural_gas_strategy.pdf

[BC MoFR and MoE] British Columbia Ministry of Forests and Range, Ministry of Environment [Internet]. 2010. Ch. 2. Soil Description. Field manual for describing terrestrial ecosystems. 2nd. Edn. Land Management Handbook 25. Province of British Columbia. Victoria [BC]. pp 1-54. Available from: https://www.for.gov.bc.ca/hfd/pubs/docs/lmh/Lmh25/LMH25_ed2_(2010).pdf

[BCOGC] BC Oil and Gas Commission. [Internet] 2011. Reclamation and remediation. Oil and Gas Commission Fact Sheet. Government of British Columbia. Victoria [BC]. Available from: https://www.bcogc.ca/node/11459/download

[BCOGC] BC Oil and Gas Commission. [Internet] 2013. Schedule B site reclamation requirements. Government of British Columbia. Victoria [BC]. Available from: http://www.bcogc.ca/node/5756/download

Brito AJ, de Almeida AT. 2009. Multi-attribute risk assessment for risk ranking of natural gas pipelines. Rel. Eng. Syst. Safe. 94 (2): 187-198.

Brockley RP. 1990. Response of thinned, immature lodgepole pine to nitrogen and boron fertilization. Can. J. For. Res. 20 (5): 579-585.

Brockley RP, Sanborn P. 2003. Effects of Sitka alder on the growth and foliar nutrition of young lodgepole pine in the central interior of British Columbia. Can. J. For. Res. 33 (9): 1761-1771.

Brown JK, Reinhardt ED, Kramer KA. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. General technical report RMRS-GTR-105. US Department of Agriculture. Ft. Collins [CO]. pp 1-20.

Brown RL, Naeth MA. 2014. Woody debris amendment enhances reclamation after oil sands mining in Alberta, Canada. Rest. Ecol. 22 (1): 40-48.

Bullock MS, Larney FJ, Izaurralde RC, Feng Y. 2001. Overwinter changes in wind erodibility of clay loam soils in southern Alberta. Soil Sci. Soc. Am. J. 65 (2): 423-430.

Bulmer C, Krzic M. 2003. Soil properties and lodgepole pine growth on rehabilitated landings in northeastern British Columbia. Can. J. Soil Sci. 83 (4): 465-474.

Byers JE. 2002. Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. Oikos. 97 (3): 449-458.

Callaway RM, Walker LR. 1997. Competition and facilitation: a synthetic approach to interactions in plant communities. Ecol. 78 (7): 1958-1965.

Campbell DB, Kiiskila S, Philip LJ, Zwiazek JJ, Jones MD. 2006. Effects of forest floor planting and stock type on growth and root emergence of Pinus contorta seedlings in a cold northern cutblock. New Forests 32 (2): 145-162.

Campbell DB, Bulmer CE, Jones MD, Philip LJ, Zwiazek JJ. 2008. Incorporation of topsoil and burn-pile debris substantially increases early growth of lodgepole pine on landings. Can. J. For. Res. 38 (2): 257-267.

Cano A, Navia R, Amezaga I, Montalvo J. 2002. Local topoclimate effect on short-term reclamation success. Ecol. Eng. 18 (4): 489-498.

Castro J, Zamora R, Hódar JA, Gómez JM, Gómez-Aparicio L. 2004. Benefits of using shrubs as nurse plants for reforestation in Mediterranean mountains: a 4-year study. Rest. Ecol. 12 (3): 352-358.

Catchpole WR, Wheeler CJ. 1992. Estimating plant biomass: a review of techniques. Aust. J Ecol. 17 (2): 121-131.

Chazdon RL. 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science. 320: 13 June 2008. 1458-1460.

Chen J, Saunders SC, Crow TR, Naiman RJ, Brosofske KD, Mroz GD, Brookshire BL, Franklin JF. 1999. Microclimate in forest ecosystem and landscape ecology: variations in local climate can be used to monitor and compare the effects of different management regimes. BioSci. 49 (4): 288-297.

Chi G, Voss P. 2005. Migration decision-making: a hierarchical regression approach. J. Region. Anal. Pol. 35 (2): 11-22.

Cieszewski CJ, Bella IE. 1989. Polymorphic height and site index curves for lodgepole pine in Alberta. Can. J. For. Res. 19 (9): 1151-1160.

Cody WJ, MacInnes KL, Cayouette J, Darbyshire S. 2000. Alien and invasive native vascular plants along the Norman Wells pipeline, District of MacKenzie, Northwest Territories. Can. Field-Nat. 114 (1): 126-137.

Coiffait-Gombault C, Buisson E, Dutoit T. 2011. Hay transfer promotes establishment of Mediterranean steppe vegetation on soil disturbed by pipeline construction. Rest. Ecol. 19 (201): 214-222.

Comeau PG, Kimmins JP. 1989. Above and belowground biomass and production of lodgepole pine on sites with differing soil moisture regimes. Can. J. For. Res. 19 (4): 447-454.

Conlin TSS, van den Driessche R. 1996. Short-term effects of soil compaction on growth of *Pinus contorta* seedlings. Can. J. For. Res. 26 (5): 727-739.

Corns IGW. 1988. Compaction by forestry equipment and effects on coniferous seedling growth on four soils in the Alberta foothills. Can. J. For. Res. 18 (1): 75-84.

Coupé R, Stewart AC, Wikeem BM. 1991. Ch. 15: Engelmann spruce – subalpine fir zone. Meidinger D, Pojar J eds. Ecosystems of British Columbia. Special Report 6. Government of British Columbia. Victoria BC. pp 223-236.

Daddow RL, Warrington GE. 1983. Growth-limiting soil bulk densities as influenced by soil texture. WSDG-TN-00005. Watershed Systems Development Group. USDA Forest Service. Fort Collins [CO]. Available from: http://wecsa.com/Refrence/GLBD1983.pdf

Davidson EA, Belk E, Boone RD. 1998. Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. Glob. Change Biol. 4 (2): 217-227.

De Bello F, Leps J, Sebastia M-T. 2006. Variations in species and functional plant diversity among climatic and grazing gradients. Ecograph. 29 (6): 801-810.

DeLong C, Annas RM, Stewart AC. 1991. Ch 16: Boreal black and white spruce zone. Meidinger D, Pojar J eds. Ecosystems of British Columbia. Special Report 6. Government of British Columbia. Victoria BC. pp 237- 250.

Densmore RV, Holmes KW. 1987. Assisted revegetation in Denali National Park, Alaska, USA. Arctic Alpine Res. 19 (4): 544-548.

Despain DG. 2001. Dispersal ecology of lodgepole pine (*Pinus contorta* Dougl.) in its native environment as related to Swedish forestry. For. Ecol. Manage. 141 (1-2): 59-68.

Desserud P, Gates CC, Adams B, Revel RD. 2010. Restoration of foothills rough fescue grasslands following pipeline disturbance in southwestern Alberta. J. Environ. Manage. 91 (12): 2763-2770.

Desserud P, Naeth MA. 2010. Promising results restoring grassland disturbances with native hay (Alberta). Ecol. Rest. 29 (3): 215-219.

Doran JW, Ziess MR. 2000. Soil health and sustainability: managing the biotic component of soil quality. App. Soil Ecol. 15 (1): 3-11.

Drahovzal SA, Loftin CS, Rhymer J. 2015. Environmental predictors of shrubby cinquefoil (*Dasiphora fruticosa*) habitat and quality as host for Maine's endangered Clayton's copper butterfly (*Lycaena dorcas claytoni*). Wetlands Ecol. Manage. 23 (5): 891-908.

Dyer SJ, O'Neill JP, Wasel SM, Boutin S. 2001. Avoidance of industrial development by woodland caribou. J. Wildl. Manage. 65 (3): 531-542.

Edmonds J. 1998. Status of woodland caribou in Alberta. Rang. Special Issue 10. 111-115.

Ehrenfeld JG, Ravit B, Elgersma K. 2005. Feedback in the plant-soil system. Annu. Rev. Environ. Resour. 30: 75-115.

Elkington TT, Woodell SRJ. 1963. *Potentilla fruticosa* L. (*Dasiphora fruticosa* (L) Rydb.). J. Ecol. 51 (3): 769-781.

Ericson RE. 2009. Eurasian natural gas pipelines: the political economy of network interdependence. Euras. Geog. Econ. 50 (1): 28-57.

Evans RD, Belnap J. 1999. Long term consequences of disturbance on nitrogen dynamics in an arid ecosystem. Ecol. 80 (1): 150-160.

Festa-Bianchet M, Ray JC, Boutin S, Côté SD, Gunn A. 2011. Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Can. J. Zool. 89 (5): 419-434.

Fisher RF and Binkley D. 2000. Ch. 9. Forest biogeochemistry. Ecology and management of forest soils. New York: Wiley and Sons. p 184-240.

Fisher RF, Binkley D. 2000. Chapter 11: Forest soil classification. Ecology and management of forest soils. 3rd ed. New York (NY): Wiley. pp 262-281.

Fissore C, Giardina CP, Kolka RK, Trettin CC. 2009. Soil organic carbon quality in forested mineral wetlands at different mean annual temperature. Soil Biol. Biochem. 41 (3): 458-466.

Foote L, Krogman N. 2006. Wetlands in Canada's western boreal forest: agents of change. For. Chron. 82 (6): 825-833.

Frey BR, Lieffers VJ, Munson AD, Blenis PV. 2003. The influence of partial harvesting and forest floor disturbance on nutrient availability and understory vegetation in boreal mixedwoods. Can. J. For. Res. 33 (7): 1180-1188.

Garshelis DL, Gibeau ML, Herrero S. 2005. Grizzly bear demographics in and around Banff national park and Kananaskis country, Alberta. J. Wildl. Manage. 69 (1): 277-297.

Gomez-Aparicio L, Zamora R, Gomez JM, Hódar JA, Castro J, Baraza E. 2004. Applying plant facilitation to forest restoration: a meta-analysis of the use of shrubs as nurse plants. Ecol. App. 14 (4): 1128-1138.

Gough L, Osenberg CW, Gross KL, Collins SL. 2000. Fertilization effects on species density and primary productivity in herbaceous plant communities. Oikos 89 (3): 428-439.

Graf MD. 2009 [Internet]. Restoration of Alberta's boreal wetlands. University of Alberta. Edmonton [AB]. Available from: http://oz.biology.ualberta.ca/faculty/stan_boutin/ilm2/uploads/footprint/Graf%20Wetland_Restoration_Review%20FINAL-Small%20File.pdf

Gray AN, Spies TA. 1995. Water content measurement in forest soils and decayed wood using time domain reflectometry. Can. J. For. Res. 25 (3): 376-385.

Gregory SV, Swanson FJ, McKee WA, Cummins KW. 1991. An ecosystem perspective of riparian zones. Biosci. 41 (8): 540-551.

Green DS. 2005. Adaptive strategies in seedlings of three co-occurring ecologically distinct northern coniferous tree species across an elevational gradient. Can. J. For. Res. 35 (4): 910-917.

Greene DF, Zasada JC, Sirois L, Kneeshaw D, Morin H, Charron I, Simar M-J. 1999. A review of the regeneration dynamics of North American boreal forest tree species. Can. J. For. Res. 29 (6): 824-839.

Grigal DF. 2000. Effects of extensive forest management on soil productivity. For. Ecol. Manage. 138 (1-3): 167-185.

Groninger J, Skousen J, Angel P, Barton C, Burger J, Zipper C. 2007. Mine reclamation practices to enhance forest development through natural succession. Forest Reclamation Advisory No. 5. Appalachian Regional Reforestation Initiative. Virginia Polytechnic Institute and State University. Blacksburg [VA]. Available from: http://www.prp.cses.vt.edu/ARRI/FRA-No5.pdf

Grubb PJ. 1977. The maintenance of species richness in plant communities: the importance of the regeneration niche. Biol. Rev. 52: 107-145.

Haeussler S, Bedford L, Boateng JO, MacKinnon A. 1999. Plant community responses to mechanical site preparation in northern interior British Columbia. Can. J. For. Res. 29: 1084–1100.

Hammermeister AM, Naeth MA, Schoenau JJ, Biederbeck VO. 2003. Soil and plant response to wellsite rehabilitation on native prairie in southeastern Alberta, Canada. Can. J. Soil Sci. 83 (5): 507-519.

Hartel PG. 1999. Ch. 2: The soil habitat. Principles and applications of soil microbiology. D.M. Sylvia, J.J. Fuhrmann, P.G. Hartel, and D.A. Zuberer. eds. Prentice Hall. NJ.

Hayhoe H, Tarnocai C. 1993. Effect of site disturbance on the soil thermal regime near Fort Simpson, Northwest Territories, Canada. Arctic and Alpine Res.25 (1): 37-44.

Heineman J. 1998. Forest floor planting: a discussion of issues as they relate to various site limiting factors. Silviculture note 16. FS 713 HFP 97/6. BC Ministry of Forests. Victoria BC.

Hiemstra CA, Liston GE, Reiners WA. 2002. Snow distribution by wind and interactions with vegetation at upper treeline in the Medicine Bow mountains, Wyoming, U.S.A. Arc. Antarc. Alp. Res. 34 (3): 262-273.

Holl KD, Aide TM. 2011. When and where to actively restore ecosystems? For. Ecol. Manage. 261 (10): 1558-1563.

Hope GD. 2007. Changes in soil properties, tree growth, and nutrition over a period of 10 years after stump removal and scarification on moderately coarse soils in interior British Columbia. For. Ecol. Manage. 242 (2-3): 625-635.

Houlahan JE, Keddy PA, Makkay K, Findlay CS. 2006. The effects of adjacent land use on wetland species richness and community composition. Wetlands. 26 (1): 79-96.

Huang WZ, Schoenau JJ. 1997. Seasonal and spatial variations in soil nitrogen and phosphorous supply rates in a boreal aspen forest. Can. J. Soil Sci. 77 (4): 597-612.

Huston M. 1979. A general hypothesis of species diversity. Amer. Natur. 113 (1): 81-101.

Ilisson T, Chen HYH. 2009. Response of six boreal tree species to stand replacing fire and clearcutting. Ecosystems 12 (5): 820-829.

Jacobs DF, Timmer VR. 2005. Fertilizer-induced changes in rhizosphere electrical conductivity: relation to forest tree seedling root system growth and function. New For. 30 (2): 147-166.

Jobidon R, Cyr G, Thiffault N. 2004. Plant species diversity and composition along an experimental gradient of northern hardwood abundance in *Picea mariana* plantations. For. Ecol. Manage. 198 (1-3): 209-221.

Johnson DW, Curtis PS. 2001. Effects of forest management on soil C and N storage: meta-analysis. For. Ecol. Manage. 140 (2-3): 227-238.

Jones P. [Internet] 1995. New reclamation standards for oil and gas wellsites in the agricultural land reserve. Proceedings of the 19th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC, 1995. The Technical and Research Committee on Reclamation. Accessed April 26 2013. Available at: https://circle.ubc.ca/bitstream/handle/2429/10855/1995%20-%20Jones%20%20New%20Reclamation%20Standards%20for%20Oil%20%26%20Gas.pdf?sequence=1

Jurgensen MF, Harvey AE, Graham RT, Page-Dumroese DS, Tonn JR, Larsen MJ, Jain TB. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity and health of interior northwest forests. For. Sci. 43 (2): 234-251.

Kalra YP, Maynard DG. 1991. Methods manual for forest soil and plant analysis. Edmonton (AB): Forestry Canada, Northwest Region. NOR-X-319.

Kalra YP, Maynard DG. 1991. 7. pH in water or CaCl2. Methods manual for forest soil and plant analysis. Forestry Canada NOR-X-319. Edmonton AB. pp 30-34.

Kappes H, Catalano C, Topp W. 2007. Coarse woody debris ameliorates chemical and biotic soil parameters of acidified broadleaf forests. App. Soil Ecol. 36 (2-3): 190-198.

Kasischke ES, Johnstone JF. 2005. Variation in postfire organic layer thickness in a black spruce forest complex in interior Alaska and its effects on soil temperature and moisture. Can. J. For. Res. 35 (9): 2164-2177.

Keddy PA, Drummond CG. 1996. Ecological properties for the evaluation, management and restoration of temperature deciduous forest ecosystems. Ecol. App. 6 (3): 748-762.

Kelty MJ. 2006. The role of species mixture in plantation forestry. For. Ecol. Manage. 233 (2-3): 195-204.

Keyes MR, Grier CC. 1981. Above and belowground net production in 40 year old Douglas-fir stands on low and high productivity sites. Can. J. For. Res. 11 (3): 599-605.

Klimešová J, Pokorná A, Klimeš L. 2009. Establishment growth and bud-bank formation in *Epilobium angustifolium*: the effects of nutrient availability, plant injury, and environmental heterogeneity. Bot. 87 (2): 195-201.

Knoepp JD, Coleman DC, Crossely Jr. DA, Clark JS. 2000. Biological indices of soil quality: an ecosystem case study of their use. For. Ecol. Manage. 138 (1-3): 357-368.

Koch JM. 2007. Restoring a jarrah forest understory vegetation after bauxite mining in Western Australia. Rest. Ecol. 15 (s4): S26-S39.

Körner C. 1998. A re-assessment of high elevation treeline positions and their explanation. Oecol. 115 (4): 445-459.

Kranabetter JM, Sanborn P, Chapman BK, Dubé S. 2006. The contrasting response to soil disturbance between lodgepole pine and hybrid white spruce in subboreal forests. Soil Sci. Soc. Amer. J. 70 (5): 1591-1599.

Krzic M, Newman RF, Broersma K. 2003. Plant species diversity and soil quality in harvested and grazed boreal aspen stands of northeastern British Columbia. For. Ecol. Manage. 182 (1-3): 315-325.

Laberee K, Nelson TA, Stewart BP, McKay T, Stenhouse GB. 2014. Oil and gas infrastructure and the spatial pattern of grizzly bear habitat selection in Alberta, Canada. Can. Geog. 58 (1): 79-94.

Lagerström A, Nilsson M-C, Wardle DA. 2013. Decoupled responses of tree and shrub leaf and litter trait values to ecosystem retrogression across an island area gradient. Plant Soil. 367 (1-2): 183-197.

Landhäusser SM, Lieffers VJ, Silins U. 2003. Utilizing pioneer species as a hydrological nurse crop to lower water table for reforestation of poorly drained boreal sites. Ann. For. Sci. 60 (7): 741-748.

Landsburg S. 1989. Effects of pipeline construction on chernozemic and solonetzic A and B horizons in central Alberta. Can. J. Soil Sci. 69 (2): 327-336.

Latham ADM, Latham MC, Boyce MS, Boutin S. 2011. Movement response by wolves to industrial linear features and their effect on woodland caribou in northeastern Alberta. Ecol. Appl. 21 (8): 2854-2865.

Lee P, Smyth C, Boutin S. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. J. Environ. Manage. 70 (2): 165-180.

Lee P, Boutin S. 2006. Persistence and developmental transition of wide seismic lines in the western boreal plains of Canada. J. Environ. Manage.78 (3): 240-250.

Légaré S, Bergeron Y, Leduc A, Paré D. 2001. Comparison of the understory vegetation in boreal forest types of southwest Quebec. Can. J. Bot. 79 (9): 1019-1027.

Lieffers VJ, Titus SJ. 1989. The effects of stem density and nutrient status on size inequality and resource allocation in lodgepole pine and white spruce seedlings. Can. J. Bot. 67 (10): 2900-2903.

Lieffers VJ, MacDonald SE. 1993. Ecology of and control strategies for *Calamagrostis canadensis* in boreal forest sites. Can. J. For. Res. 23 (10): 2070-2077.

Lieffers VJ, Beck Jr. JA. 1994. A semi-natural approach to mixedwood management in the prairie provinces. For. Chron. 70 (3): 260-264.

Lilles EB, Astrup R. 2012. Multiple resource limitation and ontogeny combined: a growth rate comparison of three co-occuring conifers. Can. J. For. Res. 42 (1): 99-110.

Lindenmayer DB, Margules CR, Botkin DB. 2000. Indicators of biodiversity for ecologically sustainable forest management. Conserv. Biol. 14 (4): 941-950.

Litaor MI, Williams M, Seastedt TR. 2008. Topographic controls on snow distribution, soil moisture, and species diversity of herbaceous alpine vegetation, Niwot Ridge, Colorado. J. Geophys. Res. 113 (G2).

Lloyd AH, Fastie CL. 2002. Spatial and temporal variability in the growth and climate response of treeline trees in Alaska. Clim. Change. 52 (4): 481-509.

Löf M, Dey DC, Navarro RM, Jacobs DF. 2012. Mechanical site preparation for forest restoration. New For. 43 (5): 825-848.

Long R. [Internet] 2003. 13. Alpine rangeland ecosystems and their management in the Qinghai-Tibetan plateau. The Yak. 2nd edn. Wiener G, Han J, Long R. eds. Food and Agriculutre Organization of the United Nations. Bangkok. Thailand. Available at: http://www.fao.org/docrep/006/ad347e/ad347e0w.htm#bm32

Lovich JE, Bainbridge D. 1999. Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environ. Manage. 24 (3): 309-326.

MacDonald AJ. 1999. Harvesting Systems and Equipment in British Columbia. Forest Engineering Research Institute of Canada. Government of British Columbia. Handbook No. HB-12. FERIC. Government of British Columbia. Victoria [BC]. 197 pp.

MacDonald SE, Fenniak TE. 2007. Understory plant communities of boreal mixedwood forests of western Canada: natural patterns and response to variable retention harvesting. For. Ecol. Manage. 242 (1): 34-48.

MacDonald SE, Quideau S, Landhäusser S. 2012. Ch. 7. Rebuilding boreal forest ecosystems after industrial disturbance. In: Vitt D, Bhatti J, editors. Restoration and reclamation of boreal ecosystems: attaining sustainable development. Cambridge (UK): Cambridge University Press. pp 123-60.

Macey DE, Winder RS. [Internet] 2001. Biological control and the management of *Calamagrostis canadensis* (bluejoint grass). Technology Transfer Note. Government of Canada.

Pacific Forestry Centre. Victoria [BC]. Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/18422.pdf

MacKendrick N, Fluet C, Davidson DJ, Krogman N, Ross M. [Internet]. 2001. Integrated resource management in Alberta's boreal forest: opportunities and constraints. Sustainable Forest Management. Project Report 2001-22: interim project report. Accessed April 24, 2013. Available at: http://ilm.law.uvic.ca/PDF/PR_2001-22.pdf

MacKenzie D. [Internet]. 2011. Best management practices for conservation of reclamation materials in the mineable oil sands region of Alberta. Available at: http://environment.gov.ab.ca/info/library/8431.pdf

MacKinnon A, Pojar J, Coupé R. 1999. Trees. Plants of northern British Columbia. 2nd edition. Lone Pine. Vancouver BC. pp 10-19.

Maestre FT. 2004. On the importance of patch attributes, environmental factors, and past human impacts as determinants of perennial plant species richness and diversity in Mediterranean semiarid steppes. Divers. Distrib. 10 (1): 21-29.

Man R, Kayahara GJ, Rice JA, MacDonald GB. 2008. Eleven-year responses of a boreal mixedwood stand to partial harvesting: light vegetation and regeneration dynamics. For. Ecol. Manage. 255 (3-4): 697-706.

Mariani L, Chang SX, Kabzems R. 2006. Effects of tree harvesting, forest floor removal, and compaction on soil microbial biomass, microbial respiration, and N availability in a boreal aspen forest in British Columbia. Soil Biol. Biochem. 38 (7): 1734-1744.

Mather WJ, Simard SW, Heineman JL, Sachs DL. 2010. Decline of planted lodgepole pine in the southern interior of British Columbia. For. Chron. 86 (4): 484-497.

Maundrell C, Hawkins C. 2004. Use of an aspen overstory to control understory herbaceous species, bluejoint grass (*Calamagrostis canadensis*), and fireweed (*Epilobium angustifolium*). North. L. Appl. For. 21 (2): 74-79.

Maynard DG, Paré D, Thiffault E, Lafleur B, Hogg KE, Kishchuk B. 2014. How do natural disturbances and human activities affect soils and tree nutrition and growth in the Canadian boreal forest? Environ. Rev. DOI: 10.1139/er-2013-0057.

Matsushima MY, Choi W-J, Chang SX. 2014. Canada bluejoint foliar δ15N and δ 13C indicate changed soil N availability by litter removal and N fertilization in a 13 year old boreal plantation. Soil Sci. Plant Nutrit. 60 (2): 208-215.

McConkey T, Bulmer C, Sanborn P. 2012. Effectiveness of five soil reclamation and reforestation techniques on oil and gas well sites in northeastern British Columbia. Can. J. Soil Sci. 92: 165-177.

McCullough DG, Werner RA, Neumann D. 1998. Fire and insects in northern and boreal forest ecosystems in North America. Ann. Rev. Entomol. 1998. 43:107–27.

McLoughlin PD, Dzus E, Wynes B, Boutin S. 2003. Declines in populations of woodland caribou. J. Wildl. Manage. 67 (4): 755-761.

Miao Z, Li C. [Internet] 2007. Biomass estimates for major boreal forest species in west-central Canada. Information report FI-X-002. Canadian Forest Service. Available from: http://cfs.nrcan.gc.ca/bookstore_pdfs/28300.pdf

Naeth MA, McGill WB, Bailey AW. 1987. Persistence of changes in selected soil chemical and physical properties after pipeline installation in solonetzic native rangeland. Can. J. Soil Sci. 67 (4): 747-763.

[NEB] National Energy Board [Internet] 2015. Marketable Natural Gas Production in Canada. Government of Canada. Ottawa [ON]. Available from: https://www.neb-one.gc.ca/nrg/sttstc/ntrlgs/stt/mrktblntrlgsprdctn-eng.html

[NRC] Natural Resources Canada [Internet] 2012. Boreal forest. Canadian Forest Service. Government of Canada. Ottawa [ON]. Available from: http://cfs.nrcan.gc.ca/pages/151

[NRC] Natural Resources Canada [Internet] 2012. Natural disturbances. Canadian Forest Service. Government of Canada. Ottawa [ON]. Available from: http://cfs.nrcan.gc.ca/pages/258

[NRC] Natural Resources Canada [Internet] 2013. Natural gas: a primer. Government of Canada. Ottawa [ON]. Available from: http://www.nrcan.gc.ca/energy/natural-gas/5641#transported

[NRC] Natural Resources Canada [Internet] 2016. Magnetic declination calculator. Government of Canada. Ottawa [ON]. Available from: http://geomag.nrcan.gc.ca/calc/mdcal-r-en.php?date=2012-06
06&latitude=54+43+58.9&latitude_direction=1&longitude=120+11+14.8&longitude_direction=-1

Nguyen-Xuan T, Bergeron Y, Simard D, Fyles JW, Paré D. 2000. The importance of forest floor disturbance in the early regeneration patterns of the boreal forest of western and central Quebec: a wildfire versus logging comparison. Can. J. For. Res. 30: 1353–1364.

Niemi GJ, McDonald ME. 2004. Application of ecological indicators. Annu. Rev. Ecol. Evol. Syst. 35: 89-111.

Nilsson M-C, Wardle DA. 2005. Understory vegetation as a forest ecosystem driver: evidence from the northern Swedish boreal forest. Front. Ecol. Environ. 3 (8): 421-428.

Niswander SF, Mitsch WJ. 1995. Functional analysis of a two year old created in-stream wetland: hydrology, phosphorous retention, and vegetation survival and growth. Wetlands 15 (3): 212-225.

Nitschke CR. 2008. The cumulative effects of resource development on biodiversity and ecological integrity in the Peace-Moberly region of northeast British Columbia, Canada, Biodivers. Conserv. 17 (7): 1715-1740.

Noble BF. 2006. Ch. 2. An overview of environmental impact assessment in Canada. Introduction to environmental impact assessment. (ON) Don Mills. Oxford University Press. pp 17-26.

Nowak S, Kershaw GP, Kershaw LJ. 2002. Plant diversity and cover after wildfire on anthropogenically disturbed and undisturbed sites in subarctic upland *Picea mariana* forest. Arctic 55 (3): 269-280.

Økland RH, Rydgren K, Økland T. 2008. Species richness in boreal forest swamps of SE Norway: the role of surface microtopography. J. Veg. Sci. 19 (1): 67-74.

Olson ER, Doherty JM. 2012. The legacy of pipeline installation on the soil and vegetation of southeast Wisconsin wetlands. Ecol. Eng. 39: 53-62.

Opio C, Van Diest K, Jacob N. 2003. Intra-seasonal changes in height to diameter ratios for lodgepole pine in the central interior of British Columbia. West. J. App. For. 18 (1): 52-59.

Osborne JW. 1999. Advantages of hierarchical linear modelling. Pract. Assess. Res. Eval. 7 (1): 1-3.

Pareliussen I, Gunilla E, Olsson A, Armbruster WS. 2006. Factors limiting the survival of native tree seedlings used in conservation efforts at the edges of forest fragments in upland Madagascar. Rest. Ecol. 14 (2): 196-203.

Peltzer DA, Bast ML, Gerry AK. 2000. Plant diversity and tree responses following contrasting disturbances in boreal forest. For. Ecol. Manage. 127 (1-3): 191-203.

Penner M. 2008. Yield prediction for mixed species stands in boreal Ontario. For. Chron. 84 (1): 1-7.

Petter TL, Evans JM, Goodrich-Mahoney JW, Mutrie D, Reinemann J. [Internet] 2009. Best Environmental Management Practices for Pipeline Construction: A Western Canadian Perspective. Available from: http://www.teraenv.com/_pdf/Tamara%20Petter_ROW%209%20Symposium%20BEMP_WC%20w-photos.pdf

Piirainen S, Finér L, Mannerkoski H, Starr M. 2007. Carbon, nitrogen, and phosphorous leaching after site preparation at a boreal forest clear cut area. For. Ecol. Manage. 243 (1): 10-18.

Pohl M, Alig D, Körner C, Rixen C. 2009. Higher plant diversity enhances soil stability in disturbed alpine ecosystems. Plant Soil. 324: 91-102.

Pojar J, Meidinger D, Klinka K. 1991. Ch. 2. Concepts. Meidinger DV, Pojar J editors. Ecosystems of British Columbia. Province of British Columbia. Ministry of Forests. Victoria BC. pp 10-37.

Pojar J, Stewart AC. Ch.18: Alpine tundra zone. In: Meidinger DV, Pojar J editors. Ecosystems of British Columbia. Province of British Columbia. Ministry of Forests. Victoria BC. pp 263-274.

Pojar J. Ch. 19. Non-tidal wetlands. In: Meidinger DV, Pojar J editors. Ecosystems of British Columbia. Province of British Columbia. Ministry of Forests. Victoria BC. pp 275-280.

Polfus JL, Hebblewhite M, Heinemeyer K. 2011. Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. Biol. Conserv. 144 (11): 2637-2646.

Prach K, Hobbs RJ. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Rest. Ecol. 16 (3): 363-366.

Prescott CE, Zabek LM, Staley CL, Kabzems R. 2000. Decomposition of broadleaf and needle litter in forests of British Columbia: influences of litter type, forest type, and litter mixtures. Can. J. For. Res. 30 (11): 1742-1750.

Prescott CE. 2002. The influence of the forest canopy on nutrient cycling. Tree Phys. 22 (15-16): 1193-1200.

Prose DV, Metzger SK, Wilshire HG. 1987. Effects of substrate disturbance on secondary plant succession; Mojave Desert, California. J. App. Ecol. 24 (1): 305-313.

Pugnaire FI, Luque MT. 2001. Changes in plant interactions along a gradient of environmental stress. Oikos. 93 (1): 42-49.

Raich JW, Tufekcioglu A. 2000. Vegetation and soil respiration: correlations and controls. Biogeochem. 48 (1): 71-90.

Rayfield B, Anand M, Laurence S. 2005. Assessing simple versus complex restoration strategies for industrially disturbed forests. Rest. Ecol. 13 (4): 639-650.

Razali NM, Yap BW. 2011. Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors, and Anderson-Darling tests. J. Stat. Model. Anal. 2 (1): 21-33.

Reeves DA, Reeves MC, Abbott AM, Page-Dumroese DS, Coleman MD. 2012. A detrimental soil disturbance prediction model for ground based timber harvesting. Can. J For. Res. 42 (5): 821-830.

Rehfeldt GE, Ying CC, Spittlehouse DL, Hamilton Jr, DA. 1999. Genetic responses to climate in *Pinus contorta*: niche breadth, climate change, and reforestation. Ecol. Monog. 69 (3): 375-407.

Reubens B, Poesen J, Danjon F, Geudens G, Muys B. 2007. The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. Trees. 21 (4): 385-402.

Roberts MR, Gilliam FS. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. Ecol. App. 5 (4): 969-977.

Roberts MR. 2004. Response of the herbaceous layer to natural disturbance in North American forests. Can. J. Bot. 82: 1273-1283.

Robertson PA, Bowser YH. 1999. Coarse woody debris in mature *Pinus ponderosa* stands in Colorado. J. Torr. Bot. Soc. 126 (3): 255-267.

Rowell MJ. 2010. Assessment of the soil resource in the reclamation of disturbed mountainous areas. Proceedings of the 5th Annual British Columbia Mine Reclamation Symposium. Cranbrook BC. University of British Columbia. Vancouver [BC]. Available from: https://open.library.ubc.ca/cIRcle/collections/britishcolumbiaminereclamationsy/11233/items/1.0042047

Rweyongeza DM, Dhir NK, Barnhardt LK, Hansen C, Yang R-C. 2007. Population differentiation of the lodgepole pine (*Pinus contorta*) and jack pine (*Pinus banksiana*) complex in Alberta: growth, survival, and responses to climate. Can. J. Bot. 85 (6): 545-556.

Sanborn PT, Prietzel J, Brockley RP 2005. Soil and lodgepole pine foliar responses to two fertilizer sulphur forms in the Sub-boreal spruce zone, central interior British Columbia. Can J. For. Res. 35 (10): 2316-2322.

Sanborn PT, Brockley RP, Mayer B. 2011. Stable isotope tracing of fertilizer sulphur uptake by Lodgepole pine: foliar responses. Can J. For. Res. 41 (3): 493-500.

Sarr DA, Hibbs DE, Huston MA. 2005. A hierarchical perspective of plant diversity. Quart. Rev. Biol. 80 (2): 187-212.

Sayer J, Chokkalingam U, Poulsen J. 2004. The restoration of forest biodiversity and ecological values. For. Ecol. Manage. 201 (1): 3-11.

Schmidt MG, MacDonald SE, Rothwell RL. 1996. Impacts of harvesting and mechanical site preparation on soil chemical properties of mixed-wood boreal forest sites in Alberta. Can. J. Soil Sci. 76 (4): 531-540.

Schneider RR, Stelfox JB, Boutin S, Wasel S. 2003. Managing the cumulative impacts of land uses in the Western Canadian Sedimentary Basin: a modeling approach. Ecol. And Soc. 7 (1).

Schoenholtz SH, Van Miegroet H, Burger JA. 2000. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. For. Ecol. Manage. 138 (1-3): 335-356.

Schoennagel T, Turner MG, Romme WH. 2003. The influence of fire interval and serotiny on postfire lodgepole pine density in Yellowstone National Park. Ecology 84 (11): 2967-2978.

Schulze E-D, Beck E, Müller-Hohenstein K. 2005. Chapter 1: Stress physiology. Plant Ecology. Springer Berlin. pp. 5-250.

Schulze E-D, Beck E, Müller-Hohenstein, K. 2005. Ch 2. Whole plant ecology. Plant ecology. Berlin: Springer. pp 253-396

Schulze E-D, Beck E, Müller-Hohenstein K. 2005. Chapter 4: Syndynamics, synchorology, synecology. Plant Ecology. Springer Berlin. pp 465-622.

Schwilk DW, Ackerly DD. 2001. Flammability and serotiny as strategies: correlated evolution in pines. Oikos 94 (2): 326-336.

Seibert J, Stendahl J, Sørensen R. 2007. Topographical influences on soil properties in boreal forests. Geoderma. 141 (1-2): 139-148.

Seip DR. 1998. Ecosystem management and the conservation of caribou habitat in British Columbia. Rang. Special Issue 10. 203-211.

Shi P, Xiao J, Wang Y-F, Chen L-D. 2014. The effects of pipeline construction disturbance on soil properties and restoration cycle. Environ. Monit. Assess. 186 (3): 1825-1835.

Silins U, Rothwell RL. 1999. Spatial patterns of aerobic limit depth and oxygen diffusion rate at two peatlands drained for forestry in Alberta. Can. J. For. Res. 29 (1): 53-61.

Simard SW, Jones MD, Durall DM, Hope GD, Stathers RJ, Sorensen NS, Zimonick BJ. 2003. Chemical and mechanical site preparation: effects on *Pinus contorta* growth, physiology and microsite quality on grassy, steep forest sites in British Columbia. Can. J. For. Res. 33 (8): 1495-1515.

Smith DW, Prepas EE, Putz G, Burke JM, Meyer WL, Whitson I. 2003. The forest watershed and riparian disturbance study: a multi-discipline initiative to evaluate and manage watershed disturbance on the boreal plain of Canada. J. Environ. Eng. Sci. 2 (S1): S1–S13.

Smith VH, Tilman GD, Nekola JC. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine and terrestrial ecosystems. Environ. Pollut. 100 (1-3): 179-196.

Soil Classification Working Group. 1998. The Canadian System of Soil Classification. Agric. and Agri-Food Can. Publ. 1646 (Revised). 187 pp.

Soon YK, Rice WA, Arshad MA, Mills P. 2000a. Effect of pipeline installation on crop yield and some biological properties of boreal soils. Can. J. Soil Sci. 80 (3): 483-488.

Soon YK, Rice WA, Arshad MA, Mills P. 2000b. Recovery of chemical and physical properties of boreal plains soils impacted by pipeline burial. Can. J. Soil Sci. 80 (3): 489-497.

Spoor G. 2006. Alleviation of soil compaction: requirements, equipment and techniques. Soil Use Manage. 22 (2): 113-122.

Stanturf JA, Madsen P. 2002. Restoration concepts for temperate and boreal forests of North America and Western Europe. Plant Biosyst. 136 (2): 143-158.

Stathers RJ, Spittlehouse DL. 1990. Forest Soil Temperature Manual. FRDA Report 130. BC Ministry of Forests and Government of Canada. ISSN 0835 0752. Victoria [BC]. 47 pp.

Strong WL, Pluth DJ, La Roi GH, Corns IGW. 1991. Forest understory plants as predictors of lodgepole pine and white spruce site quality in west-central Alberta. Can. J. For. Res. 21 (11): 1675-1683.

Sutherland B. [Internet] 2003. Preventing soil compaction and rutting in the boreal forest of western Canada: a practical guide to operating timber-harvesting equipment. For. Eng. Res. Instit. Can. Accessed October 10, 2012. Available from: http://swanvalleyforest.ca/pdfs/final_plan_appendices/APPENDIX%2017/Preventing%20Soil%

20Compaction%20and%20Rutting%20in%20the%20Boreal%20Forest%20of%20Western%20Manitoba.pdf

Swanson ME, Franklin JF, Beschta RL, Crisafulli CM, DellaSalla DA, Hutto RL, Lindenmayer DB, Swanson FJ. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. Front. Ecol. Environ. 9 (2): 117-125.

Tabachnick BG, Fidell LS. 2007. Ch. 5. Multiple regression. Using multivariate statistics. 5th edn. Boston (MA). Pearson. pp 117-194.

Tabachnick BG, Fidell LS. 2007. Ch. 15. Multilevel Linear Modeling. Using multivariate statistics. 5th edn. Boston (MA). Pearson. pp 781-857.

Tackenberg O, Poschlod P, Bonn S. 2003. Assessment of wind dispersal potential in plant species. Ecol. Monog. 73 (2): 191-205.

Takahashi M, Sakai Y, Ootomo R, Shiozaki M. 2000. Establishment of tree seedlings and water-soluble nutrients in coarse woody debris in an old growth *Picea Abies* forest in Hokkaido, northern Japan. Can. J. For. Res. 30 (7): 1148-1155.

Thiffault E, Hannam KD, Pare D, Titus BD, Hazlett PW, Maynard DG, Brais S. 2011. Effects of forest biomass on soil productivity in boreal and temperate forests- a review. Environ. Rev. 19: 278-309.

Thirukkumaran CM, Parkinson D. 2000. Microbial respiration, biomass, metabolic quotient and litter decomposition in a lodgepole pine forest floor amended with nitrogen and phosphorous fertilizers. Soil Biol. Biochem. 32 (1): 59-66.

Thomas S, Dawe RA. 2003. Review of ways to transport natural gas energy from countries which do not need the gas for domestic use. Energy 28 (14): 1461-1477.

Thompson DG, Pitt DG. 2003. A review of Canadian forest vegetation management research and practice. Ann. For. Sci. 60 (7): 559-572.

Thorpe HC, Thomas SC. 2007. Partial harvesting in the Canadian boreal: success will depend on stand dynamic responses. For. Chron. 83 (3): 319-325.

Treberg MA, Turkington R. 2010. Density dependence in an experimental boreal forest understory community. Botany 88: 753-764.

Tremblay NO, Larocque GR. 2001. Seasonal dynamics of understory vegetation in four eastern Canadian forest types. Int. J Plant Sci. 162 (2): 271-186.

[USGS] United States Geological Survey [Internet] 2013. Assessment of undiscovered conventional oil and gas resources of the Western Canadian Sedimentary Basin, Canada 2012. US Department of Interior. US Geological Survey. FS 2012-3148. Available from: http://pubs.usgs.gov/fs/2012/3148/FS12-3148-508.pdf

Uselman SM, Qualls RG, Lilienfein J. 2007. Contribution of root vs. leaf litter to dissolved organic carbon leaching though soil. Soil Sci. Soc. Am. J. 71 (5): 1555-1563.

Van Hinte T, Gunton TI, Day JC. 2007. Evaluation of the assessment process for major projects: a case study of oil and gas pipelines in Canada. Impact Assess. Proj. Apprais. 25 (2): 123-137.

Vinge T, Pyper M. 2012. Managing woody materials on industrial sites: meeting economic, ecological and forest health goals through a collaborative approach. Department of Renewable Resources. University of Alberta. Edmonton [AB] 32 pp

Walker VK, Palmer GR, Voordouw G. 2006. Freeze – thaw tolerance and clues to the winter survival of a soil community. App. Environ. Micro. 72 (3): 1784-1792.

Warren II RJ. 2010. An experimental test of well described vegetation patterns across slope aspects using woodland herb transplants and manipulated abiotic drivers. New Phytol. 185 (4): 1038-1049.

Watson K. 2009. Soils Illustrated- field descriptions. 1st edn. International Remote Sensing Surveys Ltd. Kamloops [BC].

Way DA, Oren R. 2010. Differential responses to changes in growth temperature between trees from different functional groups and biomes: a review and synthesis of data. Tree Physiol. 30 (6): 669-688.

Western AW, Zhou S-L, Grayson RB, McMahon TA, Blöschl G, Wilson DJ. 2004. Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. J. Hydrol. 286 (1-4): 113-134.

Whittaker RH. 1972. Evolution and measurement of species diversity. Taxon. 21 (2-3): 213-251.

Widenfalk O, Weslien J. 2009. Plant species richness in managed boreal forests- effects of stand succession and thinning. For. Ecol. Manage. 257 (5): 1386-1394.

Withers SP. 1999. Natural vegetation succession and sustainable reclamation at Yukon mine and mineral exploration sites. Yukon Department of Energy, Mines and Resources. Whitehorse. Yukon.

Wittmer HU, McLellan BN, Serrouya R, Apps CD. 2007. Changes in landscape composition influence the decline of a threatened woodland caribou population. J. Anim. Ecol. 76 (3): 568-579.

Wolfe SA, Nickling WG. 1993. The protective role of sparse vegetation in wind erosion. Prog. Phys. Geog. 17 (1): 50-68.

Wolken JM. Landhäusser SM, Lieffers VJ, Silins U. 2011. Seedling growth and water use of boreal conifers across different temperatures and near-flooded soil conditions. Can. J. For. Res. 41 (12): 2292-2300.

Wright EF, Coates KD, Bartemucci P. 1998. Species variability in growth response to light across climatic regions in northwestern British Columbia. Can. J. For. Res. 28 (6): 871-886.

Wright N, Hayashi M, Quinton WL. 2009. Spatial and temporal variations in active layer thawing and their implication on runoff generation in peat-covered permafrost terrain. Water Resource. Res. 45 (5): 1-13.

Wyatt S. 2008. First nations, forest lands, and "aboriginal forestry" in Canada: from exclusion to comanagement and beyond. Can. J. For. Res. 38 (2): 171-180.

Xiong S, Johanssen ME, Hughes FMR, Hayes A, Richards KS, Nilsson C. 2003. Interactive effects of soil moisture, vegetation canopy, plant litter and seed addition on plant diversity in a wetland community. J. Ecol. 91 (6): 976-986.

Xu J, Michalet R, Zhang J-L, Wang G, Chu C-J, Xiao S. 2010. Assessing facilitative responses to a nurse shrub at the community level: an example of *Potentilla fruticosa* in a sub-alpine grassland of northwest China. Plant Biol. 12 (5): 780-787.

Zabowski D, Java B, Scherer G, Everett RL, Ottmar R. 2000. Timber harvesting residue treatment: part 1. Responses of conifer seedlings, soils, and microclimate. For. Ecol. Manage. 126 (1): 25-34.

Zhao Y, Krzic M, Bulmer CE, Schmidt MG, Simard SW. 2010. Relative bulk density as a measure of compaction and its influence on tree height. Can. J. For. Res. 40 (9): 1724-1735

Zinko U, Seibert J, Dynesius M, Nilsson C. 2005. Plant species numbers predicted by a topography based groundwater flow index. Ecosys. 8 (4): 430-441.

Zummo LM, Friedland AJ. 2011. Soil carbon release along a gradient of physical disturbance in a harvested northern hardwood forest. For. Ecol. Manage. 261 (6): 1016-1026.

Appendix 1. Soil Analysis

Laboratory/Analysis	Reference and analysis Description
BC MoE Laboratory	
Efective CEC	Hendershot WH, Lalande H, Duquette M. 1993. Ch. 19. Exchangable cations and effective CEC by the BaCl2 method. Soil sampling and methods of analysis. Carter MR. editor. CRC Press. (FL): Boca Raton. pp 168-169 Hendershot WH, Lalande H, Duquette M. 2008. Ch. 18. Soil chemical analyses: ion exchange and exchangable cations. Soil sampling and methods of analysis. 2nd edition. Carter MR, Gregorich EG. 2008. editors. CRC Press. (FL): Boca Raton. pp 197-206
Total Sulphur	
Available Phosphorous	Kalra YP, Maynard DG. 1991. Easily extractable phosphorous: Bray 1 (dilute acid-flouride) procedure. Methods manual for forest soil and plant analysis. Forestry Canada. (AB): Edmonton. NOR-X-319. pp 74-76 John MK. 1970. Coloric determination of phosphorous in soil and plant materials with ascorbic acid. Soil Sci. 109 (4): 214-220
Particle Size Analysis	Kroetsch D, Wang C. 2008. Soil physical analyses: Particle size distribution. Soil sampling and methods of analysis. 2nd edition. Carter MR, Gregorieh EG. 2008. Canadian society of soil science. CRC Press Roca Baton FL. p 713
Total C, total N	Kalra YP. 1998. Handbook of reference methods for plant analysis. CRC Press. (FL): Boca Raton. pp 81-83 Rutherford PM, McGill WB, Arocena JM, Figueirdo CT. 2008. Soil Chemical analyses: Total nitrogen. Soil sampling and methods of analysis. 2nd edition. Carter MR, Gregorich EG. 2008. editors. Canadian society of soil science CRC Press. (FL): Boca Raton. p 198 Skjemstad JO, Baldock JA. 2008. Soil Chemical analyses: Total and organic carbon. Soil sampling and methods of analysis. 2nd edition. Carter MR, Gregorich EG. 2008. editors. Canadian society of soil science. CRC Press Boca Raton FL. p 198

Appendix 2. Complete list of species planted in Ojay research blocks

Research Block	Cover Type	Genus	Species	n. Planted 2010
BWBS 1	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticosa*	200
		Dryas	*drummondii*	1200
		Hedysarum	*boreale*	23
		Aster	*alpinus*	30
BWBS 2	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticosa*	400
		Dryas	*drummondii*	45
		Hedysarum	*boreale*	23
		Juniperus	*horizontalis*	18
		Arctostaphylos	*uva-ursi*	30
		Aster	*alpinus*	40
BWBS 3	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticosa*	400
		Betula	*pumila*	600
		Hedysarum	*boreale*	23
		Aster	*alpinus*	40
BWBS 4	Canopy	*Pinus*	*contorta*	60
		Picea	*mariana*	100
		Larix	*laricina*	340
	Understory	*Dasiphora*	*fruticosa*	600
		Betula	*pumila*	400
ESSF 1	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticasa*	400
		Hedysarum	*boreale*	30
		Dryas	*drummondii*	1200
		Aster	*alpinus*	30
ESSF 2	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticasa*	400
		Dryas	*drummondii*	1200
		Aster	*alpinus*	30
		Arctostaphylos	*uva-ursi*	N/A

		Juniperus	*horizontalis*	N/A
ESSF 3	Canopy	*Pinus*	*contorta*	100
		Picea	*glauca x engelmannii*	60
	Understory	*Dasiphora*	*fruticosa*	200
		Betula	*pumila*	400
		Hedysarum	*boreale*	23
		Juniperus	*horizontalis*	18
		Arctostaphylos	*uva-ursi*	30
		Aster	*alpinus*	40
ESSF 4	Canopy	*Pinus*	*contorta*	60
		Picea	*mariana*	60
		Picea	*glauca x engelmannii*	60
		Larix	*laricina*	60
	Understory	*Dasiphora*	*fruticosa*	600
		Betula	*pumila*	400

Appendix 3. Alternative Species Diversity Index including Planted Lodgepole Pine and Shrubby Cinquefoil

Appendix 3A. Cover by Plant Type Including Planted Lodgepole Pine and Shrubby Cinquefoil

Means and standard error (in parentheses) of percent vegetative cover by plant type in Control, Pine and Cinquefoil plots. For Control plots n = 9 (all blocks); Pine plots BWBS 1,2,3 and ESSF 1,2,3 n = 8, BWBS 4 n = 3, ESSF 4 n = 4; Cinquefoil plots BWBS 1,2,3 and ESSF 1,2,3, 4; n = 3 each block, BWBS 4 n = 2.

Block	Treatment	Tree	Shrub	Herb	Graminoid	Other*
BWBS 1	Control	1.00 (0.00)	1.38 (1.12)	3.05 (3.15)	4.38 (3.20)	1.00 (0.00)
	Pine	3.00 (1.15)	2.11 (1.36)	4.52 (5.29)	4.12 (4.80)	1.33 (0.58)
	Cinquefoil	0	12.60 (10.14)	3.00 (3.51)	2.62 (2.06)	0
BWBS 2	Control	0	1.67 (0.58)	2.45 (1.79)	3.36 (2.11)	3.33 (3.21)
	Pine	3.11 (1.27)	1.86 (0.69)	6.91 (10.18)	3.89 (3.34)	1.00 (0.00)
	Cinquefoil	0	6.43 (6.80)	2.43 (1.81)	3.86 (2.91)	1.00 (0.00)
BWBS 3	Control	0	2.78 (1.39)	11.51 (19.55)	5.18 (5.76)	2.00 (1.00)
	Pine	5.22 (3.83)	5.14 (6.41)	5.98 (8.51)	5.08 (3.70)	3.33 (1.53)
	Cinquefoil	0	11.67 (8.76)	12.64 (13.37)	6.67 (2.89)	4.00 (1.41)
BWBS 4	Control	0	1.85 (1.21)	1.50 (0.52)	4.60 (2.28)	3.40 (3.56)
	Pine	3.67 (1.15)	6.00 (6.22)	1.60 (0.89)	4.20 (3.56)	7.00 (3.46)
	Cinquefoil	0	4.80 (3.56)	2.25 (0.96)	8.14 (5.24)	6.00 (4.62)
ESSF 1	Control	1.17 (0.41)	2.50 (3.12)	2.71 (2.52)	2.22 (2.95)	3.00 (0.00)
	Pine	2.25 (1.28)	2.25 (2.41)	3.17 (2.50)	1.65 (0.70)	4.80 (5.85)
	Cinquefoil	1.00 (0.00)	12.83 (12.09)	2.75 (2.06)	1.25 (0.50)	1.00 (0.00)
ESSF 2	Control	1.25 (0.50)	6.75 (6.95)	2.63 (3.07)	2.00 (1.55)	0
	Pine	2.88 (0.99)	7.00 (11.90)	6.47 (5.17)	1.46 (0.66)	1.47 (0.74)
	Cinquefoil	0	15.25 (12.53)	1.00 (0.00)	1.00 (0.00)	0
ESSF 3	Control	1.00 (0.00)	2.33 (1.15)	5.56 (5.32)	1.82 (1.60)	0
	Pine	2.89 (2.26)	3.15 (2.70)	6.72 (8.61)	6.60 (6.01)	1.00 (0.00)
	Cinquefoil	0	7.00 (8.16)	8.29 (7.00)	6.00 (5.10)	0
ESSF 4	Control	1.00 (0.00)	5.71 (6.72)	9.56 (17.61)	13.80 (16.21)	22.33 (23.63)
	Pine	3.60 (2.88)	4.00 (3.70)	5.93 (9.95)	5.85 (7.90)	21.64 (25.96)
	Cinquefoil	1.00 (0.00)	7.56 (9.03)	7.15 (9.66)	14.57 (16.45)	30.00 (0.00)

* "Other" designation was used for mosses, lichens, and unidentifiable plants.

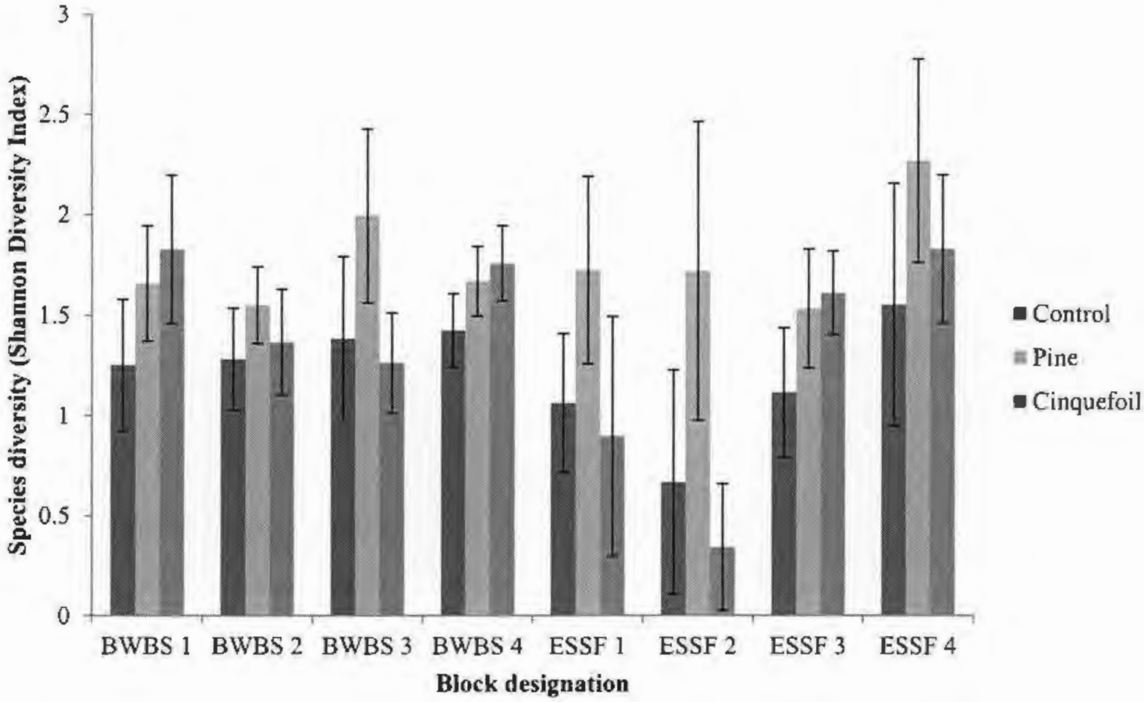
Appendix 3B. Count by Plant Type Including Planted Lodgepole Pine and Shrubby Cinquefoil

Means and standard error (in parentheses) of count by plant type observed in Control, Pine, and Cinquefoil plots. For Control plots n = 9 (all blocks), Pine plots BWBS 1,2,3 and ESSF 1,2,3 n = 8, BWBS 4 n = 3, ESSF 4 n = 4; Cinquefoil plots BWBS 1,2,3, n = 3, BWBS 4 n = 2; and ESSF 1,2,3, and 4, n = 3 each block.

Block	Treatment	Tree	Shrub	Herb	Graminoid	Other*
BWBS 1	Control	1.00 (0.00)	2.69 (5.23)	8.78 (9.46)	14.56 (13.76)	2.13 (2.47)
	Pine	9.8 (6.21)	2.78 (1.86)	15.70 (18.11)	10.94 (13.79)	1.33 (0.58)
	Cinquefoil	0	52.00 (49.09)	10.5 (14.20)	11.84 (15.86)	0
BWBS 2	Control	0	1.00 (0.00)	7.45 (6.44)	5.68 (5.44)	10.33 (9.50)
	Pine	10.44 (5.85)	3.71 (4.08)	16.91 (17.61)	9.83 (10.26)	1.50 (1.00)
	Cinquefoil	0	38.14 (43.42)	9.86 (11.41)	10.29 (7.54)	1.00 (0.00)
BWBS 3	Control	0	2.33 (1.80)	7.69 (8.07)	6.91 (6.92)	4.00 (5.20)
	Pine	8.11 (3.48)	4.81 (4.34)	10.12 (14.48)	11.00 (11.66)	3.67 (1.53)
	Cinquefoil	0	40.00 (49.07)	12.57 (13.59)	23.33 (23.09)	1.50 (0.71)
BWBS 4	Control	0	1.92 (0.95)	7.69 (8.53)	19.50 (7.59)	2.47 (2.64)
	Pine	11.33 (4.16)	7.75 (8.42)	5.00 (8.40)	14.60 (10.53)	12.83 (13.63)
	Cinquefoil	0	30.40 (38.37)	5.00 (3.56)	28.57 (13.45)	5.50 (5.20)
ESSF 1	Control	2.17 (1.17)	5.88 (5.33)	8.86 (8.32)	2.11 (1.62)	20.00 (0.00)
	Pine	8.88 (4.49)	6.69 (8.66)	14.43 (12.01)	4.00 (2.76)	18.00 (17.89)
	Cinquefoil	1.00 (0.00)	43.00 (48.92)	9.00 (7.16)	2.5 (1.29)	10.00 (0.00)
ESSF 2	Control	1.00 (0.00)	9.25 (12.28)	5.50 (5.15)	1.50 (0.84)	0
	Pine	10.75 (5.12)	9.00 (6.63)	19.11 (12.91)	2.31 (1.49)	6.33 (2.29)
	Cinquefoil	0	53.50 (38.77)	3.00 (1.73)	2.00 (1.00)	0
ESSF 3	Control	1.00 (0.00)	6.33 (3.21)	12.68 (9.58)	3.00 (1.34)	0
	Pine	6.67 (4.21)	8.77 (12.17)	15.00 (16.42)	6.53 (4.31)	1.00 (0.00)
	Cinquefoil	0	26.50 (36.19)	19.86 (17.65)	6.86 (7.52)	0
ESSF 4	Control	2.00 (1.41)	4.81 (3.66)	12.72 (16.11)	13.07 (16.80)	2.17 (3.95)
	Pine	9.40 (7.30)	7.00 (4.98)	13.20 (17.21)	7.69 (7.89)	10.93 (12.96)
	Cinquefoil	1.00 (0.00)	20.22 (25.02)	10.38 (11.72)	5.86 (5.48)	1.00 (0.00)

* "Other" designation was used for mosses, lichens, and unidentifiable plants

Appendix 3C. Diversity Index Values Including Planted Lodgepole Pine and Shrubby Cinquefoil



Mean Shannon Diversity Index (H') values for Control, Pine and Cinquefoil plots, including planted individuals in Pine and Cinquefoil plots, all blocks.